SIMPLE SCIENCE

By E. N. DA C. ANDRADE, D.Sc., Ph.D.
Quain Professor of Physics in the University of London

and JULIAN HUXLEY, M.A.
Lately Professor of Zoology in the University of London

Pictures by L. R. BRIGHTWELL
and COMERFORD WATSON

BASIL BLACKWELL OXFORD

First printed - - September, 1934
Reprinted - - - December, 1934
Reprinted - - - April, 1936

AN INTRODUCTION TO SCIENCE
BOOK I

Things Around Us

By E. N. DA C. ANDRADE
D.Sc., Ph.D., F.R.S.
Quain Professor of Physics in the University of London

and JULIAN HUXLEY, M.A., D.Sc.

With Drawings by L. R. BRIGHTWELL

BASIL BLACKWELL OXFORD

First printed March, 1932
Reprinted August, 1932
Reprinted August, 1933
Reprinted September, 1934
Reprinted April, 1937
Reprinted July, 1939
Reprinted November, 1941
Reprinted April, 1944
Reprinted May, 1945
Reprinted July, 1946
Reprinted July, 1947
Reprinted September, 1949

PRINTED IN GREAT BRITAIN

CONTENTS—BOOK I

CONTENTS

CHAPTER I

WHAT IS SCIENCE?

INTERESTING THINGS AROUND US

ALL around us, whether we live in town or country, interesting things are happening. Engines are working, some moving about and pulling trains, others fixed down and turning the machines, called dynamos, which make electricity, or working looms for making cloth, or rollers for rolling steel plate or rails, or doing a hundred other important things. Some men are hard at work making metals from the rocks and the earths, called ores, which contain them, although these ores have about them nothing bright and shining which looks like a metal. Bridges and buildings and ships are being made with the steel won from the earth, which while red-hot is shaped by rollers into beams and bars. Table knives are being manufactured from a different kind of steel: tools for cutting metal from another kind of steel, made especially hard by putting other metals with the iron: magnets from another kind yet. Other men are busy at the very different task of taking photographs, and others are making from these photographs metal plates to print pictures in books and newspapers. Other men still are making dyes of all kinds, to colour our clothes and our curtains and our carpets, or soap of various sorts, or soda, or other chemical substances, some kinds in small quantities for medicines, and other kinds by the ton for use as manure on fields. In the country men are growing crops of

every description, to provide food for the table, and flowers and fruit trees, some for the gardens of people who live in towns and like to see things growing.

Anyone who has noticed what is going on around us knows that, although man is very clever at making things, Nature produces even more wonderful results. In every field and in every pond all kinds of living things, insects, animals and plants, are growing, changing shape and colour each in its own particular way as time goes on. The butterflies come from crawling grubs, each plant comes from a little seed, and although the seeds of several different kinds of plants may appear alike at first, anyone who looks at them carefully finds that each sort of plant has its own particular kind of seed. Each seed must contain some secret workings which make a particular variety of stalk and leaf come from it. The bright and beautiful and varied colours which Nature makes in flowers can in many cases be imitated exactly by men who have studied the science of chemistry, but we do not yet fully understand the easy way in which the plant itself makes them.

Man can make a piece of land grow wheat instead of weeds, or see to it that two blades of grass grow where only one grew before, but they do not make the seed or arrange how it is to change into a plant. They only arrange for it to have water and suitable soil and light. What the seed does by itself, in sprouting and growing and producing stems and flowers or fruit, and then making new seeds for itself, is much more wonderful than the working of any of our engines and is more difficult to understand, although many of the rules which seeds and plants obey have been found out. There are many other astonishing things that happen regularly The tides rise and fall all round the coast. The seasons of spring, summer, autumn

and winter follow each other year after year, each with its own changes in plant and animal life. In spring, for instance, birds build nests and lay eggs: the eggs hatch out and the young birds grow up. In autumn, the leaves fall from the trees. Plants make nectar in their flowers, and bees visit them, take the nectar and turn it into honey and store it in the hives. Meanwhile the bees produce wax out of their own bodies, and with it make little chambers to serve as storehouses for the honey and nurseries for the young bee grubs. All round the year water falls out of the sky as rain, and runs off the country to sea in streams and rivers, which cut into the land as they flow. Such things, and hundreds of others which many people do not trouble to notice or think about, happen all round us, without depending on man or his inventions.

The Stars in their Courses

Things that happen on the earth are not the only wonders that we can look at and study. Anyone who has watched the sky at night knows that, however wonderful the motions of our machines may be, they are not as grand as the march of the stars across the heavens, and the changes in appearance of the moon from night to night. If we only looked now and then at the sky, not paying much attention, it might seem that the moon was always changing shape without rule, and that sometimes it had vanished completely. But if we notice carefully night after night we soon find out that it goes regularly from a narrow crescent to a wider crescent, then to a full disc, and then decreases again to a narrow crescent, after which it begins all over again. The nights on which it cannot be seen at all are those on which there are heavy clouds, which are very much closer to us than the moon, and hide it from us, just as a

curtain may prevent us seeing, from a room, a distant street lamp. Every twenty-eight days the moon goes through all the shapes from the narrow new moon back again to the narrow new moon. Twenty-eight days is therefore called a lunar month, since *luna* is the Latin word for moon.

Again, to the person who takes no interest the sky may appear full of stars, very much alike and all arranged anyhow, never the same two nights running, just as the grains of a handful of sand thrown on a white cloth will arrange themselves differently each time. Actually a careful look at the beautiful display on clear nights soon makes it plain that the stars are of very different brightness and appearance, and form patterns which are always the same. It soon becomes easy to find out particular stars and particular groups. If on some nights there appear to be fewer stars, it is only because when there is fog or mist in the air the fainter stars cannot be seen through it. The stars are really there in the day as well as at night, but when the sun is shining the light is so strong that the much weaker stars cannot be seen. In just the same way you will find that the flame of a spirit lamp, which can easily be seen in a room away from the window, is very hard to see in bright sunlight, and many people still believe that sunshine falling on a fire will put it out, simply because the flame looks paler in the bright light.

A star or a star pattern which we can pick out will not, however, always appear in the same part of the sky, but the general rule which the movement of the stars obeys can easily be found. All of the stars seem to move round together, as if painted on the inside of a hollow ball, with the earth as its centre. Once we have learnt to recognise a group of stars we shall find that that group always has the same arrangement, like the towns on a railway map of

England, which keep the same distance from one another as we move the map about. A group of stars that is very easy to recognise is the seven stars arranged something in the shape of a saucepan, or dipper, with a handle, as shown in Fig. 1. The group is sometimes called The Dipper, from this shape: other people call it Charles' Wain, because it looks something like a cart, or wain, with a shaft. Other people call it (or really the larger group to which it belongs) The Great Bear. It is always to be seen, on clear nights, somewhere to the North, but at one time of night it is "right way up," at other times on end or upside down, as it travels round. Try to imagine the two stars which make the side of the saucepan away from the handle, marked *a* and *b* in the picture, joined by a line, and that line drawn out away from the bottom of the saucepan. This will show another star—and a very important one for us—on that line, about five times as far from *a* as *b* is, on the other side. That star is due North, and is called the Pole Star. It does not move during the night: all the other stars seem to turn round it, like the horses of a merry-go-round turning round the central pole. That is one of the rules of the stars, and helps us to find any star later in the night. All the stars move slowly round the Pole Star,

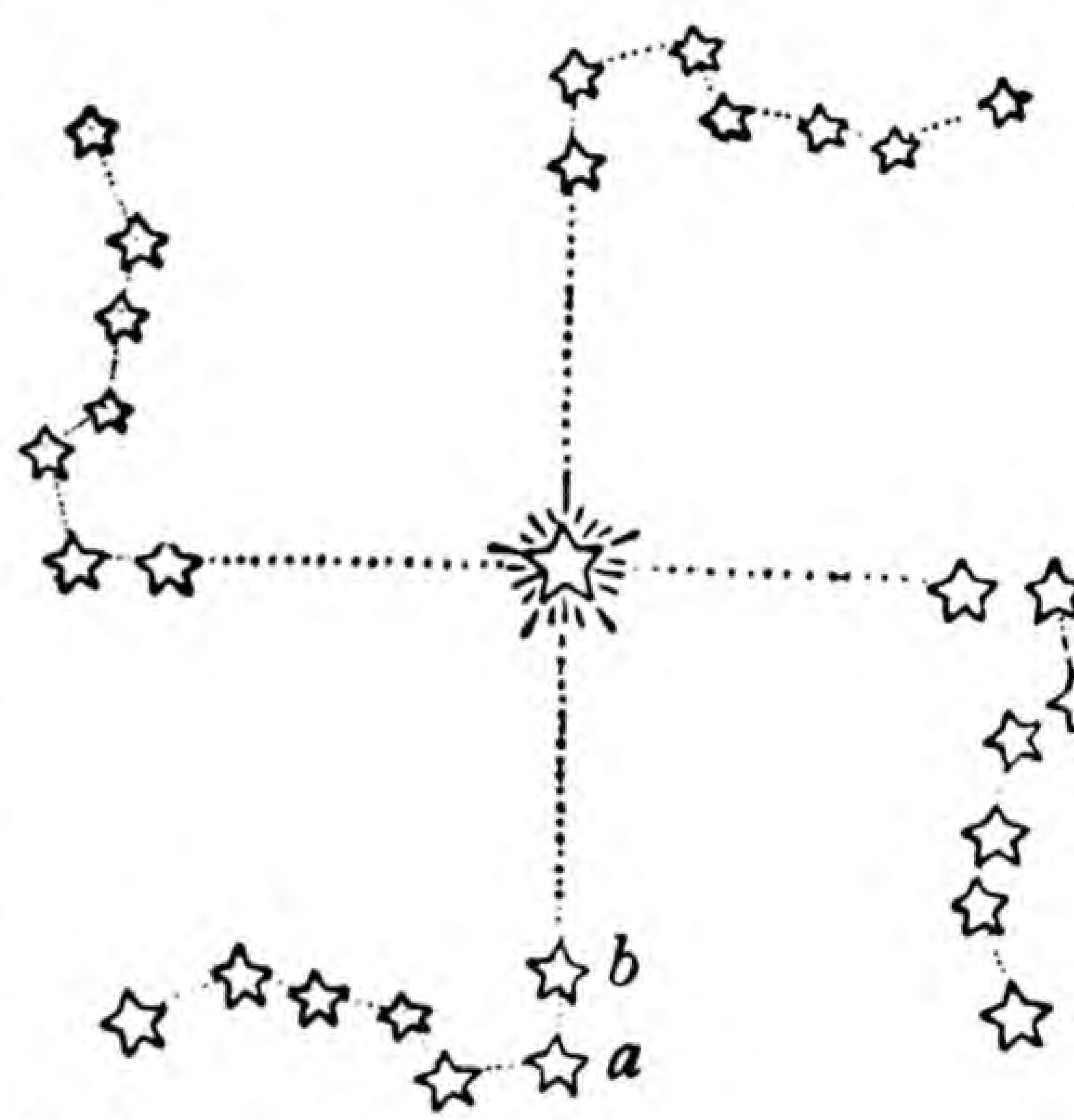


FIG. 1.—*Four different positions of the group of stars called the Dipper at different times. The Pole Star is in the middle.*

going up, or rising, in the east and setting in the west. Fig. 2 shows some of the groups of stars which can be seen near the Pole Star, with their names.

The Planets and their Satellites

But besides the stars there are other bright bodies in the sky which are often called stars, but whose proper name is *planets*. Venus, often called the "evening star" (although not really a star), is the easiest one to recognise. These planets move about among the stars and week by week travel from being near one group of stars to being near another, although in the end each of them goes right round the heavens to its starting place and so on again. The motion of these planets is, then, also regular, as if worked by a machine. The earth itself is a planet. Long, long ago, before steam engines, before telescopes, before printing, before gunpowder, before even most of our tools, such as the saw, were invented, men noticed the regular movements of the heavenly bodies, and puzzled themselves to find out the rules which they obeyed. They were convinced that there were rules, and that the planets did not behave as if they were sheep wandering about at random, but like parts of a machine. The exact rules were not found out until the great Sir Isaac Newton came to study the subject in the reign of King Charles II; but the important thing is that the rules are so accurately known that it is now possible to work out where the moon, sun and planets will be at any time, and so, for instance, to tell beforehand when the moon will get between the sun and the earth, which is what is called an eclipse of the sun.

The moon is much closer to the earth than any other heavenly body: the sun is nearly four hundred times as far off, and only looks about the same size because it is

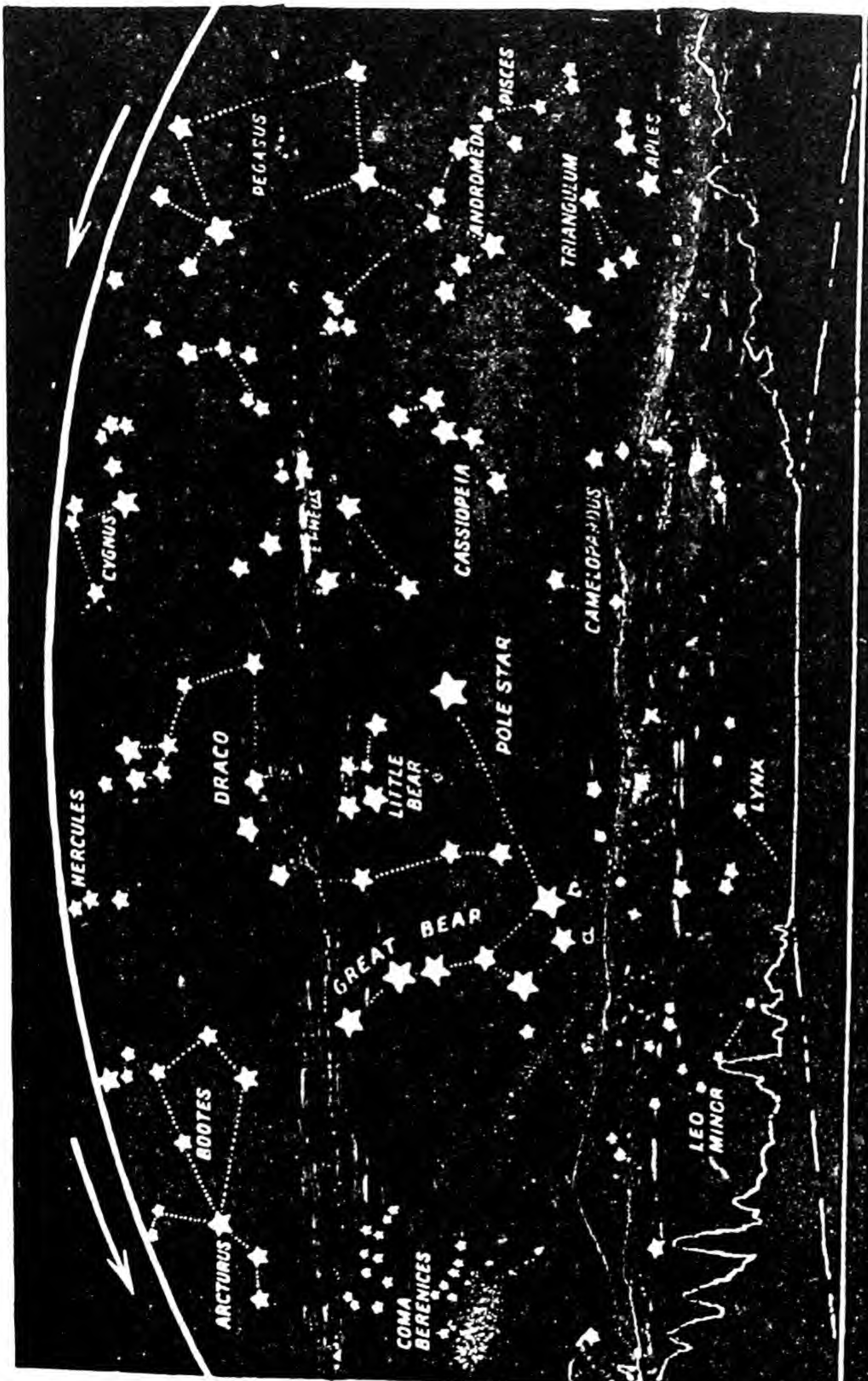


FIG. 2.—*Some of the star groups which can be seen near the Pole Star. The dots show imaginary lines, connecting stars which people in olden days grouped together. There is nothing actually making the stars in a group belong to one another. Arcturus and Algol are bright single stars*

just about four hundred times as big across. The moon may be said to belong to the earth, because she goes round and round the earth, once in every twenty-eight days, much as if the sun and the other planets were not there. A heavenly body that is near a planet and goes round it is called a satellite, so the moon is the earth's satellite. Other planets have more than one satellite: the largest planet, Jupiter, has no fewer than nine moons of its own.

All Things obey Rules

A child of seven knows that any engine works regularly according to rules, and that if it is supplied with the right fuel—coal for most steam engines, petrol for motor cars—and properly oiled and cared for it will do its task in exactly a certain way. A locomotive, for instance, is capable of pulling a certain load at a certain speed on the flat. Should an engine go wrong we do not suppose that it is bewitched, but that some part of it is worn, broken, or misplaced. Two engines that are built and managed in exactly the same way must be able to do exactly the same jobs, both equally well: if one works a little better than the other it means that there must be some slight difference in the size or strength of some parts, or else that a clever engineer is altering the timing of the stroke, or doing something else a little differently from the engineer running the first engine.

Again, the man with a camera knows that it has rules of its own. It is not chance that gives a good photograph, but a proper focussing of the lens, and a correct exposure. The lens is made up of pieces of glass, round on each side, which bend the light in such a way that a little picture of the scene is formed on the photographic plate. A simple magnifying glass will give a picture of a bright window or

sunlit scene on a piece of white paper held in the hand or fastened on the opposite wall of the room. The picture is made by the light being bent on passing from air to glass: the same kind of bending of light makes a stick look crooked when it is partly in water. People who understand the rules which light obeys on passing through curved glass surfaces can make lenses that behave better than ordinary magnifying glasses, and give clearer pictures. The more expensive camera lenses are better thought out and better made than the cheaper ones, but it sometimes happens that a cheap lens has some little accidental curve, owing to hurried manufacture, which makes it form a very good picture. If, of two lenses, one makes a sharper picture than the other, it means that there is some little difference in manufacture or arrangement.

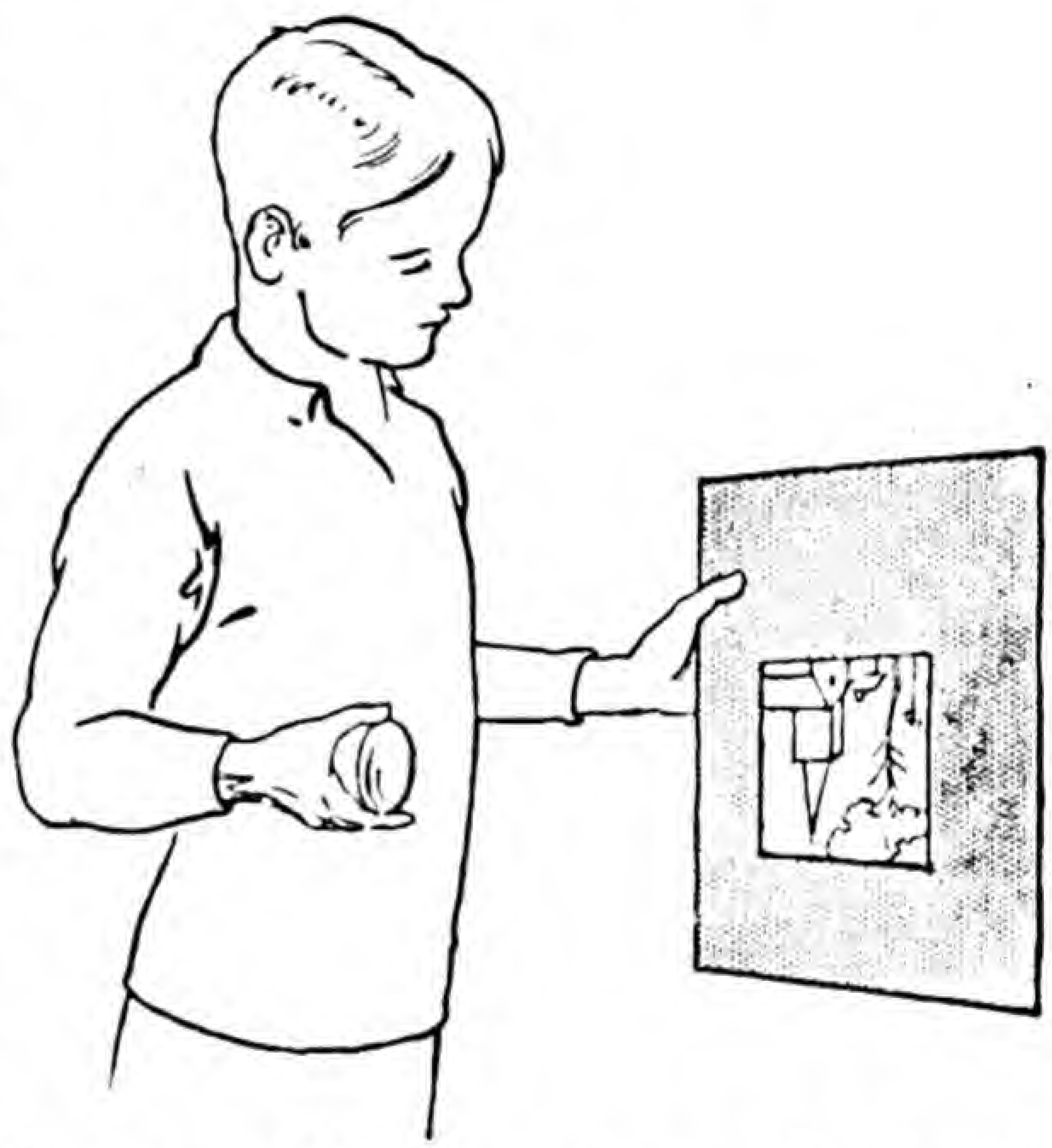


FIG. 3.—*Making a picture of a bright scene by means of a lens.*

In a very wonderful way the picture made by the camera lens is recorded by the photographic plate, which answers to the light falling on it. When a picture is to be taken the lens is uncovered by a shutter of some kind, so that the light from the scene in front of the camera makes a picture of that scene on the plate, and the shutter is then quickly closed again so that other light does not make other pictures, and spoil the first one. If the picture

is a snapshot the lens may only be uncovered for a hundredth of a second or so. "Exposing" the plate means letting the light from the scene fall on it in this way: a correct exposure means that the lens was not left open either for too short or for too long a time. Then comes the development and fixing of the plate, which is a matter of using certain chemicals according to rules. Each chemical has a distinct thing to do, which has been worked out by men of science.

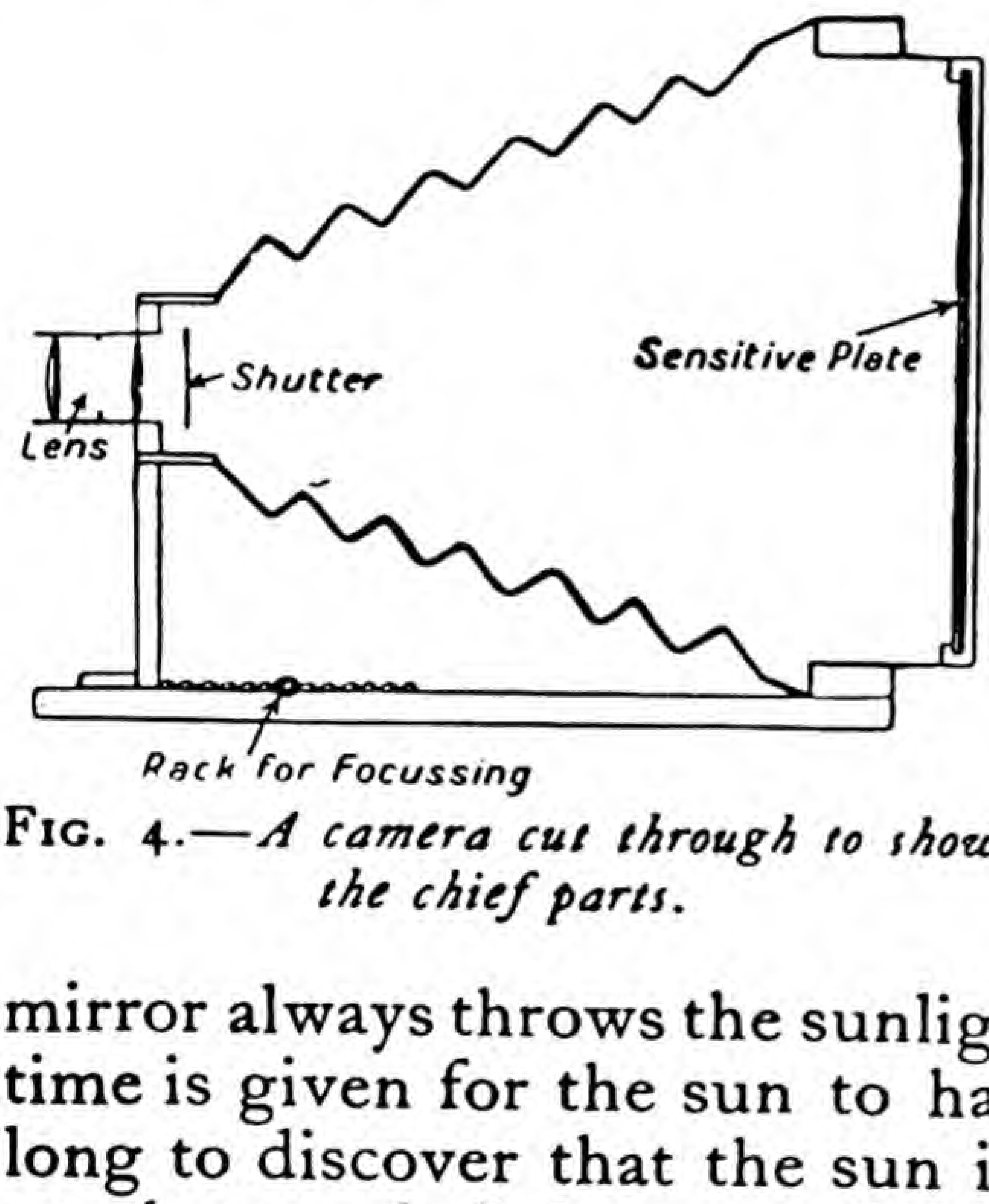


FIG. 4.—*A camera cut through to show the chief parts.*

In the camera light goes through lenses according to rules. When light is reflected it also obeys rules, very simple ones. Take a little piece of looking glass and try to flash the sun on to a particular part of the wall; you will find that the same position of the mirror always throws the sunlight in the same place, unless time is given for the sun to have moved. It will not take long to discover that the sun is reflected from the mirror much as a ball bounces from a flat floor or wall. The slope at which it strikes the mirror is equal to the slope, on the other side, at which it leaves the mirror. This is a simple rule of light, and when it is grasped you will be able to put the mirror straight off so as to throw the sun where you want it.

The man who has to make a new kind of dye does not pour a lot of things together and hope that it will turn out well. He has studied chemistry, and knows

that there are rules for what happens when different kinds of chemicals are put together, and from these rules he reasons what is likely to happen. If it does not come off as he expected he knows that he must have made a mistake, and tries to find the reason: he does not say that he has failed because someone has put a spell on him, or because he saw a black cat that morning.

FIG. 5.—*Studying the direction of the beam reflected from a mirror.*

THINGS ARE NOT ALWAYS WHAT THEY SEEM

Things are not always what they seem, and first impressions must be carefully checked if they seem surprising. For instance, we cannot turn one metal into another, yet if a knife or a piece of bright iron is dipped into a certain blue liquid it seems, when it has come out, to be turned into copper. But it is not. The blue liquid is copper sulphate dissolved in water; and copper sulphate is made from copper dissolved in sulphuric acid. Copper is there, then, in the liquid, but in a hidden form. When the iron is dipped in, some of the copper comes and settles on it, so that when it is withdrawn the iron is coated with bright copper and seems to have changed its nature. In the old days people used to pretend to turn silver into gold by showing a piece of gold coated with silver, and saying that

it *was* silver. The lump was then put into a liquid, and, behold, it became gold. What really happened was that the liquid, which was an acid, dissolved off the silver and showed the gold. The simple rule that one metal cannot be turned into another is really true, and the things that seem to contradict it are really examples of other rules.

Just as the copper in the blue liquid is disguised, so a great many other substances exist around us in disguise, and before they can be revealed the rules which they obey have to be known. Lighting gas is hidden in coal. If some little pieces of coal are placed in the bowl of a long

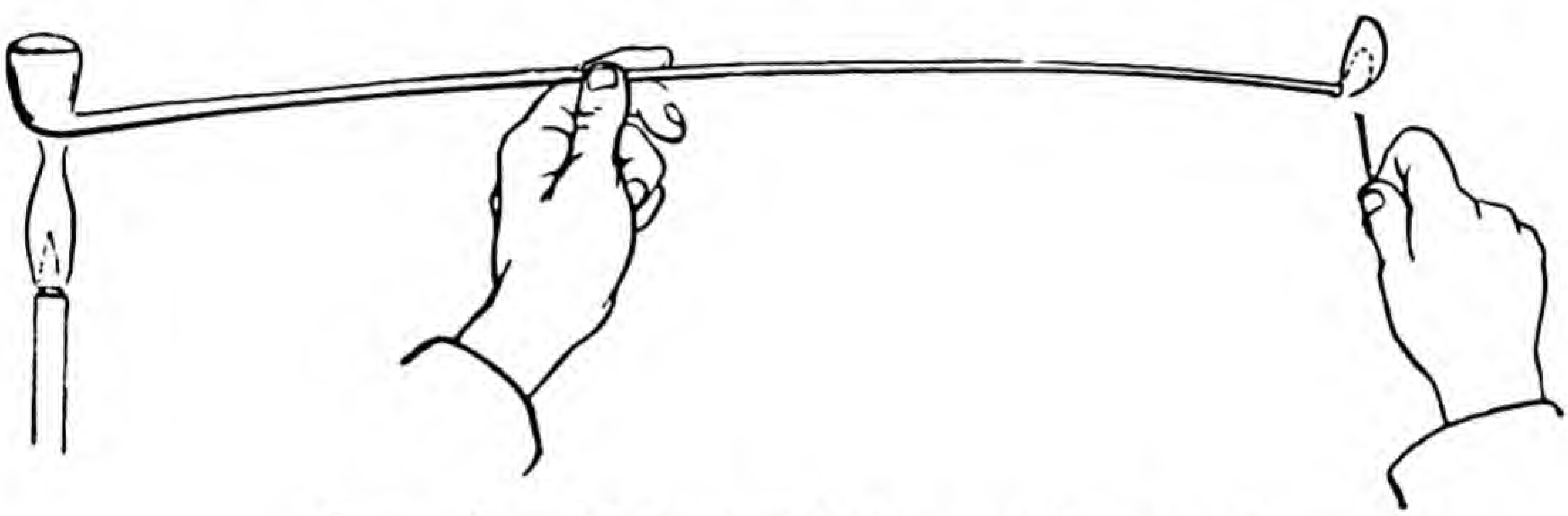


FIG. 6.—*Making lighting gas from coal.*

clay pipe, the top of the pipe closed with a little clay, and then the pipe bowl strongly heated in a gas flame or a spirit lamp, the gas will come from the coal and pass along the stem of the pipe, which is its only way out; we can light it at the end of the stem. This, though of course on a big scale, is how gas is actually made. Stranger still, from some of the black sticky stuff left in the bowl—coal-tar, as it is called—most beautiful dyes can be made if the right rules are followed.

The aluminium of which many of our saucepans are made is hidden in ordinary clay and certain other kinds of peculiar earth: to make it from a special kind of earth by

electricity great factories have been set up in Scotland. Red lead does not look like lead, but actually is mostly lead, and can be made from lead, or lead can be made from it, by following certain rules. Things are not always what they seem, but one or two rules can explain a great many mysteries.

Some Rules about Heat

Can you boil water in a glass tube, holding the tube in your hand, without a handle of any kind? If you hold the tube at the top and let the flame play on the bottom of the tube, the water under your fingers will soon get so uncomfortably hot that you cannot hold on. If, however, you hold the tube at the bottom you can boil the water at the top without warming the water at the bottom enough to notice. This is not magic: it is a result of the simple rule that a liquid takes up more room when it is hot than when it is cold. A piece of liquid of a certain size is therefore lighter when hot than when cold, so hot liquid rises, or floats up, through cold. When you heat the liquid at the bottom of the tube, as fast as it gets hot it rises to the

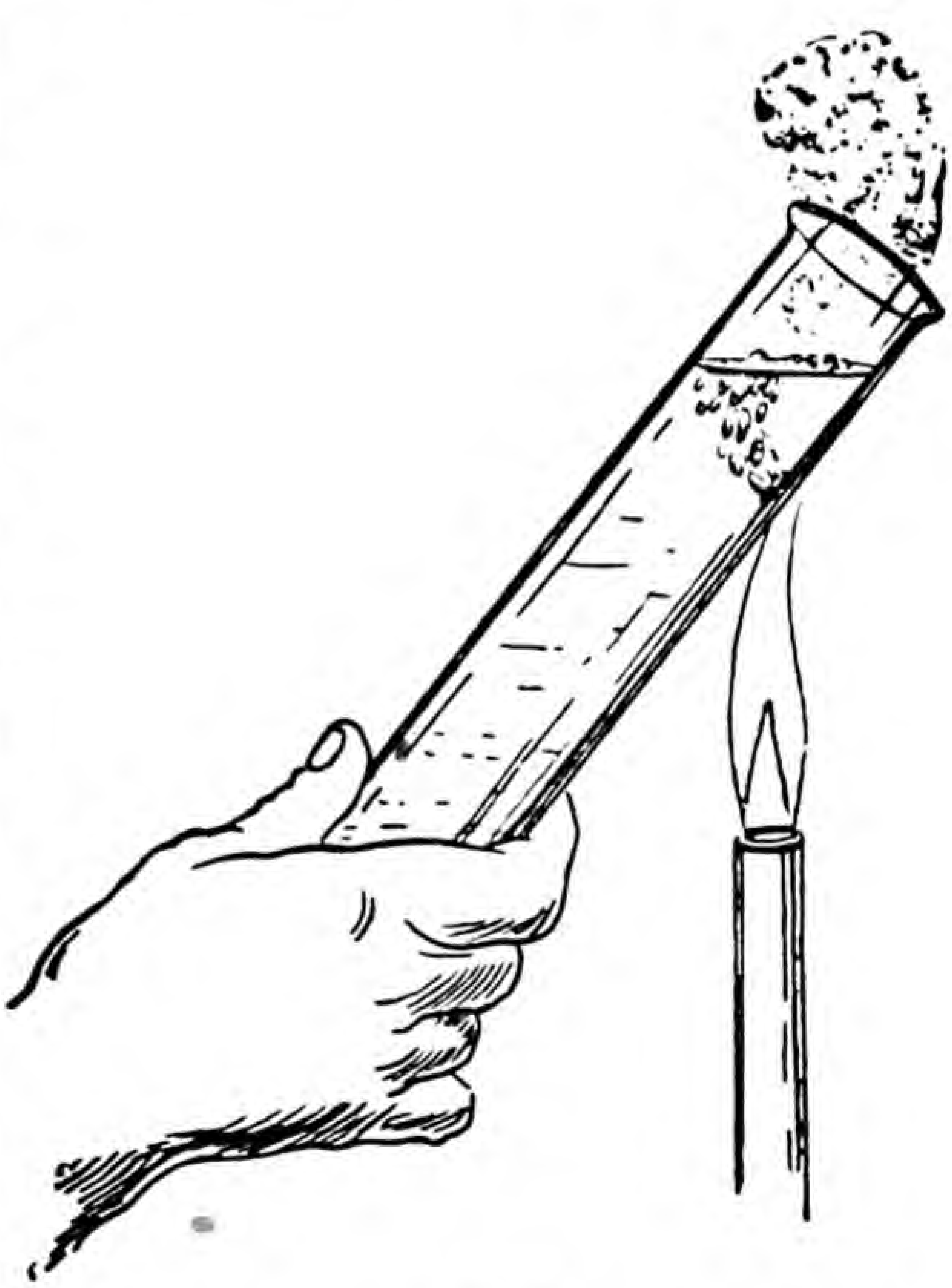


Fig. 7.—*How to boil water in a tube without burning your hand.*

top, so that the liquid gets well mixed and soon is too hot to bear. When you heat it at the top, the hot, light liquid is on top already, and stays there, while the cold, heavy liquid remains at the bottom. This simple rule is used in constructing boilers for great ships, in working out the heating of large buildings by hot water, and for many other important purposes. Hot air also rises in the same way as hot water: if you stand on a chair or a table in a kitchen or hot room you will be surprised to find how hot the air near the ceiling is. Air that has been breathed comes out warm and goes to the top of the room, so that to ventilate a room the windows should be opened a little, not at the bottom, but at the top to let out the used air as it rises.

Now for some other simple rules of heat. The water in a kettle on a stove gets hotter and hotter until it boils. Suppose it is now beginning to boil and is left on the stove, will it get hotter still? We can find out by taking its temperature with a thermometer (only we must be careful not to use an ordinary bath thermometer, or a doctor's thermometer, as these are not made to take such high temperatures and would break if put in the kettle). We should then find that, once the water begins to boil, it stays at the same temperature. But we can convince ourselves of this in a simpler way. Put three glassfuls of cold tap water in a bowl, and pour into it one glassful of boiling water from a kettle that has just boiled, and we find that we can put our hands in the mixed cold and boiling water, and judge how hot it is. Now suppose that we again put three glassfuls of cold tap water in the bowl, but that, instead of water from a kettle that had just boiled, we pour in a glassful from a kettle that has been boiling for ten or twenty minutes; we then find that, testing with our hands, the mixture is no hotter than the one made with the

freshly boiled water, so that the long-boiled water contains no more heat than the new-boiled water.

What happens is that the heat which goes in after the water is just boiling does not make the water any hotter, but just makes some of it boil away to steam. It is this fact that boiling water stays at the same temperature that makes boiling such a useful way of cooking, because we need not trouble whether the fire is fierce or not: so long as it keeps the water boiling, the potatoes, or what not, in the water cannot get hotter than the fixed temperature at which the water boils. The effect of fifteen minutes' boiling is always the same, while the effect of fifteen minutes in the oven depends upon whether it is a hotter or colder oven. This simple rule of boiling is very important for steam engines, but for steam engines we also have to take into account that the boiling water is shut up under pressure in the boiler, and the effect of this pressure is a matter for other rules of heat which come later.

Things always Behave in the Same Way—if Everything about Them is the Same

From these examples of the way things behave according to rules, the great lesson we learn is that the same things always behave in the same way if everything around is the same—that is, if all the conditions are the same. If we notice something which seems to be a contradiction of this chief rule we shall always find that there is really something, some little queerness, which has escaped us—that there is a catch, as we should say if it were a riddle—and that when we have found out the catch there is really no contradiction. For instance, a sheet of ordinary paper, which is made of linen pulp or wood pulp, or the kind of Spanish grass called esparto, always burns if held in a

flame. Suppose now you see a sheet of paper held in a flame, and it does not burn, you will conclude either that it is not ordinary paper or not an ordinary flame. The flame can be tested by putting a sheet of ordinary paper in it. If this burns, the flame is all right, and the paper must be peculiar. The secret is that a coarse paper which will not burn can be made from the white stringy mineral called *asbestos*, and if you examine it you will be able to rub the fibres of asbestos out of it. In a flame it simply glows red-hot. It is used for wrapping round hot pipes in engines and such like, to keep the heat in.

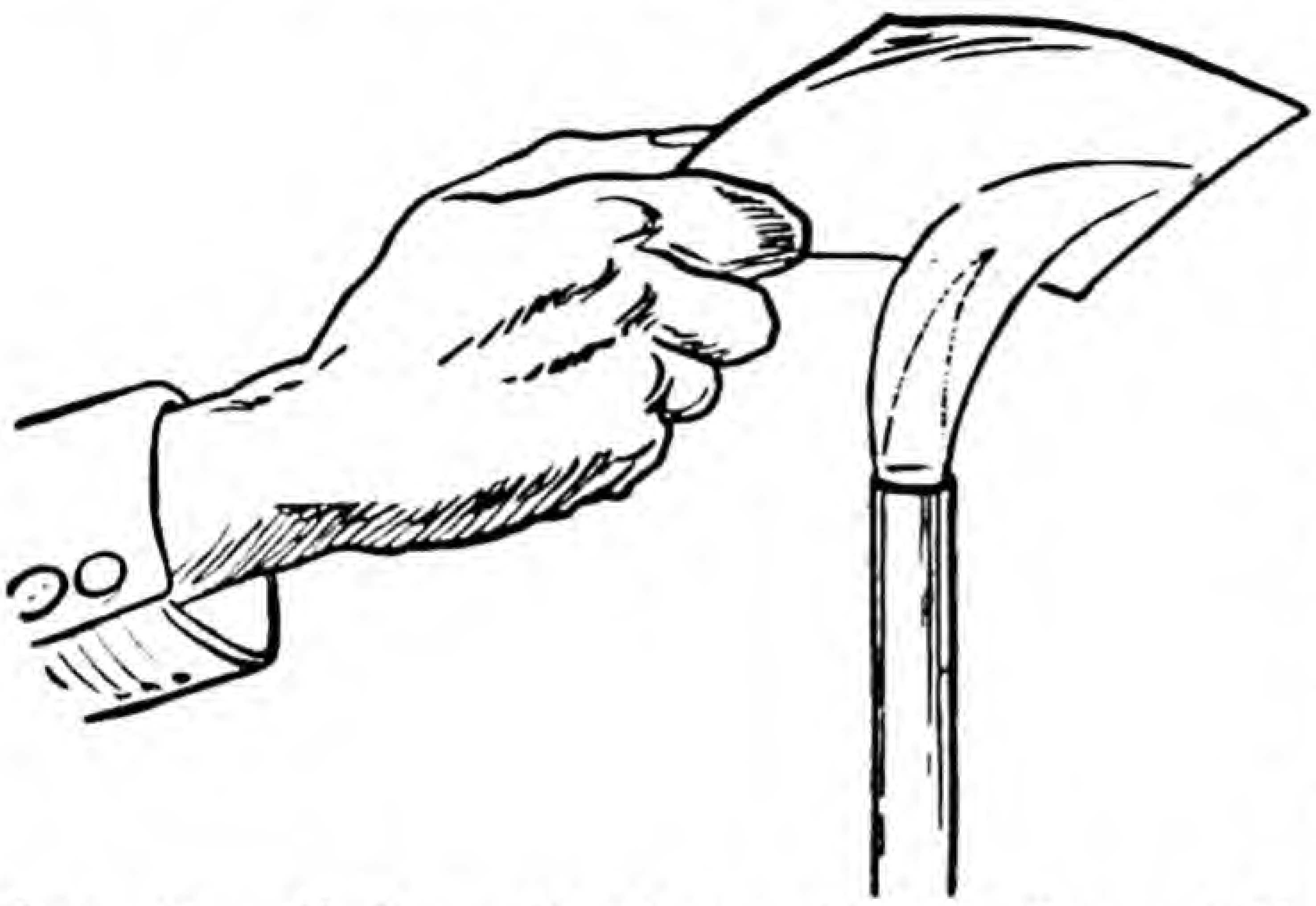


FIG. 8.—"*Paper" that will not burn. The sheet that looks like coarse paper is really asbestos.*

Sugar dissolves in water. Suppose a lump of stuff that looks like sugar be put into a liquid which looks like water, but does not dissolve when stirred, then either we are not dealing with sugar or not dealing with water: it might be a lump of marble, which looks like sugar, dropped into water, or a lump of sugar dropped into alcohol, which looks like water. (Alcohol is a colourless liquid or spirit. It is made into methylated spirit by adding other liquids, of unpleasant taste, to prevent people drinking it. Some colouring matter is usually added as well.)

In some parts of the country water makes soapsuds very easily, while in other parts the same soap makes hardly any suds at all. This looks at first as if water could have

different properties in different places; but this is not possible. What really happens is that in some places the water has certain things dissolved in it from lying in the ground, or running over special kinds of soil, and that it is these things which prevent the soap from making suds freely. It is easy to show this. First of all, rain water, which falls pure from the skies, makes suds easily in all parts of the country: it is just simple water, or "soft water," as people call it. Secondly, if we take rain water, or other soft water, and boil it all away in a porcelain basin, nothing will be left in the vessel, but if we take some "hard water," which does not make suds, and boil it all away, a brownish crust will remain behind in the vessel, which is the stuff dissolved in the water, left dry when all the water goes off as steam. Also, when water is first boiled, but not all boiled away, part of the dissolved stuff comes out of the water and forms a crust. This crust can be found in any old kettle, and is called "fur" by housewives: in places where the water is hard the kettles "fur" far more easily than in places where it is soft. This "fur" gives a lot of trouble in boilers.

So we see that water does not really have different properties in different places. There is only one way in which water behaves with soap, or with anything else, but different things which cannot be seen, dissolved in the water, have special effects. In just the same way a little sugar dissolved in the water makes it taste sweet, or a little salt makes it taste sharp, though we cannot see any difference. Spring water tastes brisk and clean because it has a special kind of air dissolved in it, not because it is an ordinary water with special virtues. If the spring water be boiled all this air comes out, and when the water is cold again it tastes flat.

Iron sinks in water. Yet we can make a needle float on

water if we place it very carefully on the surface. Some people do this by floating a piece of cigarette paper on the water, and at once placing the needle on it. When the paper becomes sodden and sinks, the needle is left floating. How is this? It is because the surface of all liquids behaves as if there was a skin stretched tightly over it, as we can see by filling up a glass carefully until it is more than full. The water bulges higher than the top, just as if tied in with a cover.

FIG. 9.—*Floating a needle on water.*

This skin, however, is not strong: we can break it at the edge with a feather, and the water will overflow. It is strong enough to carry a needle, or a light insect, for many insects, like the water-skaters, can run on the surface of water. It cannot, however, carry a penny, or anything heavy like that. If the needle breaks through the skin it sinks at once like any other iron or steel body. This skin rule tells us something about liquids which we have to take into account if we want to understand how light things behave on the surface of liquids.

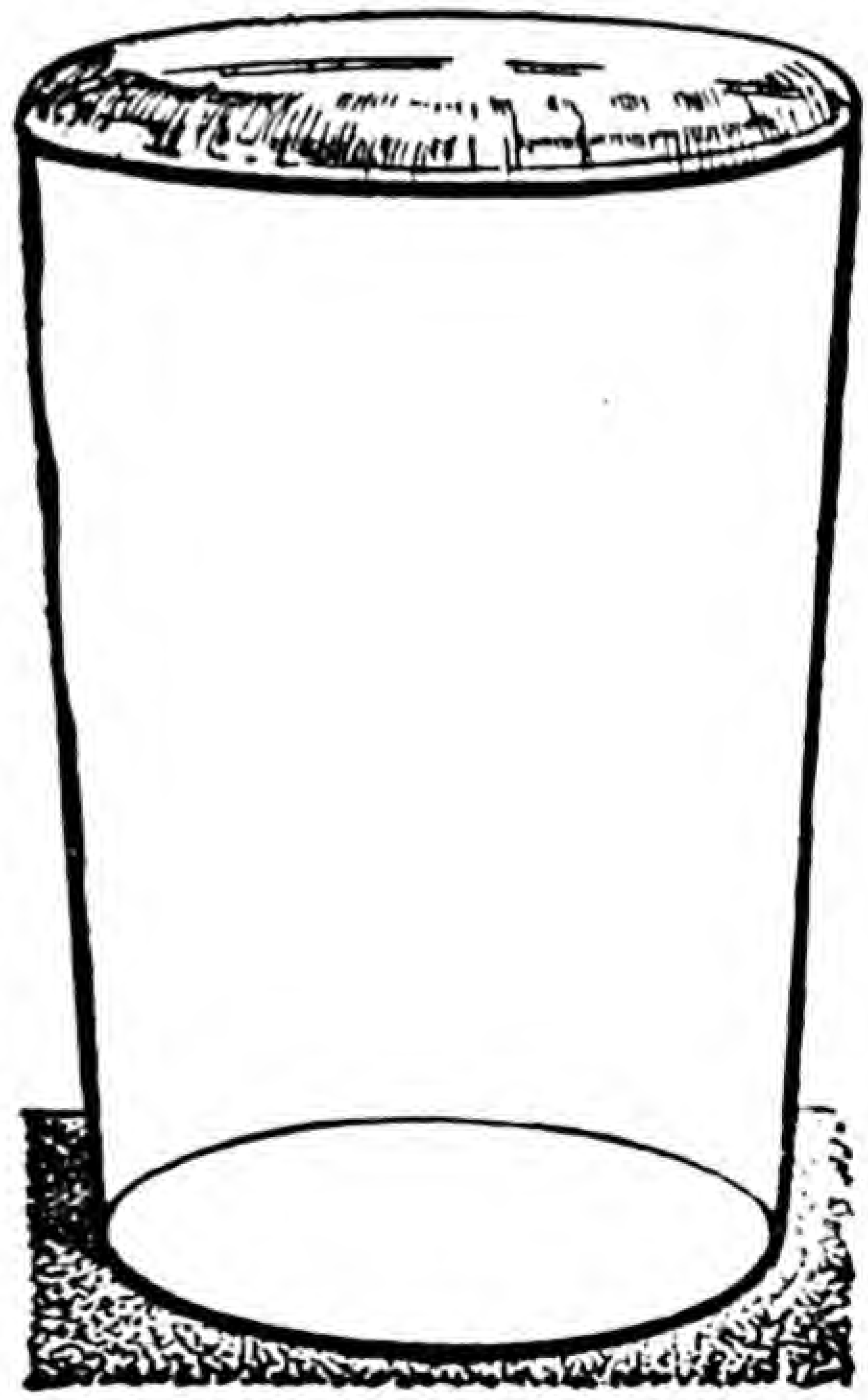


FIG. 10.—*By filling a glass very carefully the water can be made to bulge higher than the top, as if it were covered by a skin.*

WHAT SCIENCE MEANS

The things about which we have been talking all show us that there

really are rules which govern the behaviour of all things. Now we can begin to answer our own question, *What is Science?* In Science we learn about these rules, and, when we are puzzled by what we see, try to explain our observations by thinking over the old rules of Nature which men already know, or else by discovering some new rules. One part of science is observation, which means noticing things, and the other part is trying to find out what the things which we notice mean. Nature is something like a game of cricket. Just as to a man who knows nothing about science everything seems happening without rule or reason, so to a man who knows nothing about cricket the game appears to be fifteen men (eleven in the field, two batsmen and two umpires) behaving in an aimless way. With more careful observation, however, he will soon begin to find that there are rules. For instance, he will see that the fielders and the umpires do not walk across just when they feel like it, but after the man with the ball has delivered it six times. Of course he will be very puzzled at first as to why sometimes there are seven balls, until he finds out about wides and no-balls. In just the same way in science we are sometimes surprised that one of our rules seems to break down: then we have to search about for some new rule not before discovered. Again, the foreigner watching cricket will be surprised that sometimes the man who strikes the ball runs, and sometimes he does not, until he notices that there are two kinds of occasion when he does not run; firstly, for a little hit which does not give him time to run from one wicket to the other, and, secondly, for a very big hit, which reaches the boundary. When he has got a good idea of the rules he will find the game very interesting, and in the end he will, perhaps, want to play himself, or at any rate to advise

the players. In the same way the more we find out about the rules of Nature, firstly by reading of them in books, and secondly by noticing ourselves, the more interesting engines and electricity and light and sound and flowers and wind and stars become. They all have their laws, and if at any time they do not seem to obey laws it is because we have not yet found out all there is to know about them.

There are a great many different kinds of things to study, and there are different branches of science which are each busy with one particular group of things or happenings. These different branches of science have different names of their own. The study of the stars, planets and other heavenly bodies is called *Astronomy*, and the men who follow it, *astronomers*.

The study of the calculations which enable us to answer questions as to exactly *how far* and *how long* and *how quickly* and *how big*, in all branches of science, is called *Mathematics*, and the men who carry out the calculations, *mathematicians*. *Arithmetic* is one kind of Mathematics, *Algebra* is another kind, *Geometry* another kind, *Trigonometry*, which deals with calculating angles, another kind, and there are many other kinds of which you will not yet have heard. Before any bridge or ship or railway can be built, or before the time of the new moon and of the tides to be expected can be printed, a lot of mathematics has to be done.

The study of how different kinds of things act on one another to form a new kind of thing, or of how heat breaks up one kind of body into different things, is called *Chemistry*. For instance, when the bright knife was put into the blue solution of copper sulphate, and the iron brought the copper out, we were dealing with chemistry. Finding out why fats, boiled with substances called alkalis, make soap,

is chemistry, and so is the study of how lighting gas is made from coal, and bright dyes from the coal-tar left behind with the coke when the gas has gone. Simpler still, the study of the other kind of gas, called carbon dioxide, which is put into mineral drinks to make them bubble and sparkle, and of the way it is made and combines with other things, is chemistry.

Making up one new kind of thing from many other things, and breaking down one kind of thing into many things, is the task of chemistry, and the things made by its aid vary from the stuff called amyl acetate, which is used to flavour your pear drops and gives them their peculiar smell, to washing soda and artificial manure, from aspirin tablets to sugar. The men who study chemistry are called *chemists*. The men who keep what are generally called chemists' shops should really be called pharmacists. It does not matter if we go on calling them chemists as long as we remember that the real chemist is the man who studies the science of chemistry. Nearly all the things in the chemist's shop are made by the help of chemistry.

The study of electricity and of heat and of light and of sound and of some other things like these is called *Physics* —not to be mixed up with physic, which is another name for medicine. In physics we study what happens to things that are not living and that do not change into something else, as happens in the processes studied in chemistry. Electricity drives machines and heats wires, but the machines and wires do not change their nature. Heat makes railway lines expand, but it does not change them into something else. Light is reflected from mirrors, but does not change the mirror.

Wireless telegraphy, and ordinary telegraphy by wires, and X-rays and electric light and telescopes and micro-

scopes owe their discovery and perfection to the study of physics. Photography is partly physics and partly chemistry: the construction of the camera and lens, which is all about light, is physics, and the development of the plate, which is changing one kind of thing in the plate to another, by means of chemicals, is chemistry. The men who study physics are called *physicists*.

There are many other kinds of science that deal with things that are not living, but Mathematics, Astronomy, Physics and Chemistry are the most important, and Mathematics, Physics and Chemistry come in in all the other sciences. There are also sciences which deal with living things, and we will now turn to them.

The Science of Living Things

It has been easy to see that engines have rules, and nearly as easy to understand that the planets follow rules, and go round the sky as if by clockwork, and that light has rules which it follows when it goes through lenses and is reflected at mirrors, and heat has rules, and electricity has rules, and sound has rules, and, in fact, that all things which are not living have scientific laws which they obey: you might think, I say, that all this is true, but that things that live are outside science, and that all things which concern them do not have rules which they obey. Reflect a moment, however, and you will begin to see scientific order in the living world, too. Plants, for instance, do not appear without seeds having been sown. When weeds begin to grow on a piece of land in the middle of a city where nobody has ever sown a seed, or, as sometimes happens, on the top of a high wall, it is certain that seeds have been carried by the wind to that place. Nothing grows without a seed. Further, every kind of plant has its own

particular seed, and when that seed is sown, and kept supplied with the water and other things which it needs, it always grows into a plant by the same stages. A seed needs air besides water, although you might not think it, as the seed is buried in the earth. A certain amount of air is dissolved in ordinary water, and so can get to the seed as the water filters through the soil. Plant seeds in two pots each containing dry earth or sawdust, and water one pot with ordinary water and the other with water which has been boiled to drive out all the dissolved air, and then allowed to cool—the seeds that have been watered with the boiled water will not sprout, or germinate as it is called.

We can find plenty of other rules about plants. For instance, whichever way up a seed is planted, and in whichever direction it may *start* to grow, the plant always comes up out of the earth, and does not grow sometimes up, sometimes down. A plant kept from the sunlight never turns green, but stays white: celery and asparagus are kept white by piling up the earth round the growing stem. The sun is also in part responsible for the colours of ripe fruit. Letters and little pictures can be made to appear in natural colours on a growing apple by covering it with a bag with spaces cut in so as to let the sun through only where you want the red colour.

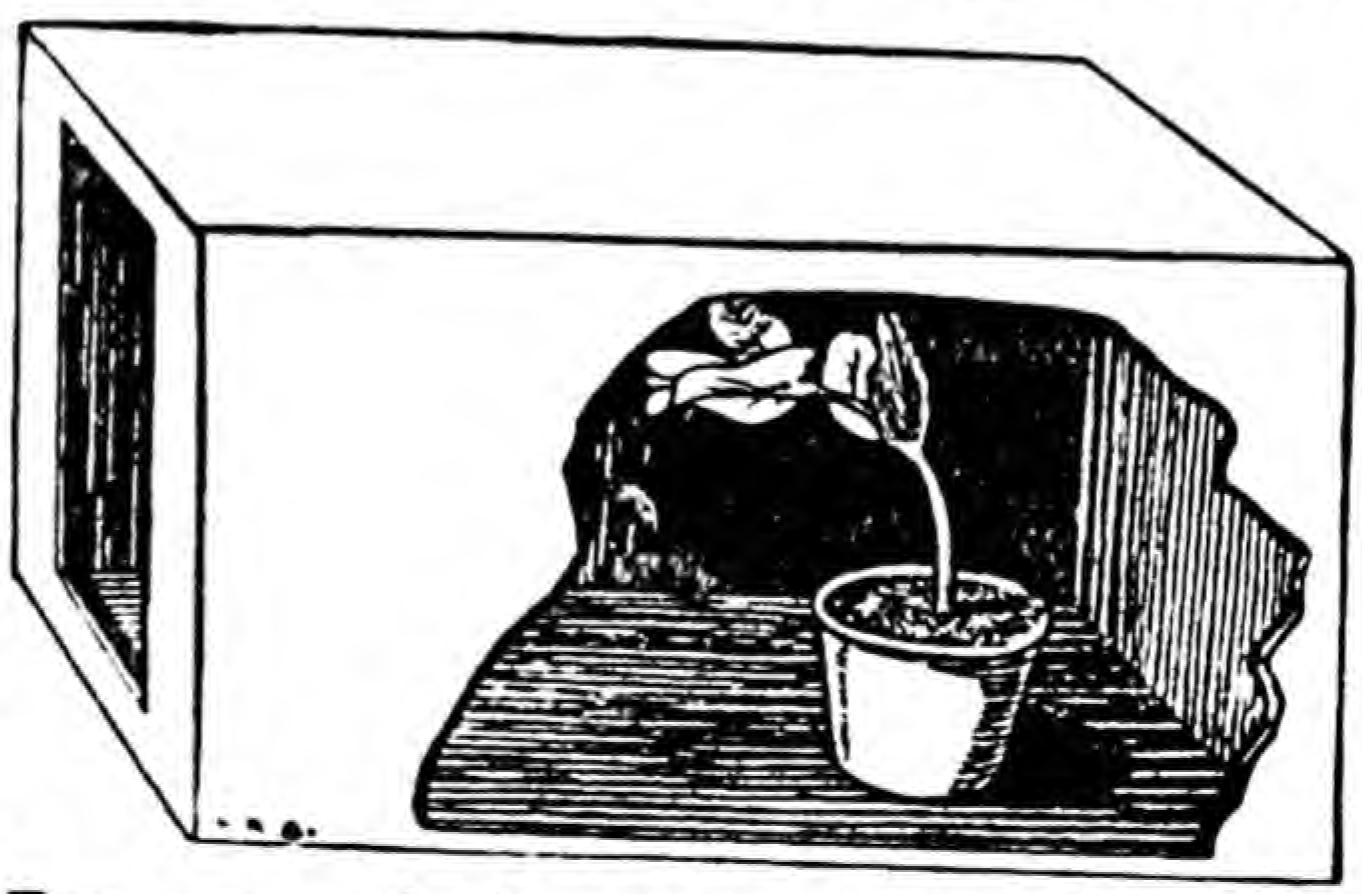


FIG. 11.—*A plant grown in a box open at one end only. It grows bent towards the light. (The side of the box, which is actually closed, is drawn as if broken away, to show the plant.)*

Green plants generally turn to the light. Of course in

the ordinary way as the sun moves round the sky the plant receives light from all southerly directions in the course of the day, and as it takes some time for the plant to turn it grows more or less straight up, with a general lean to the south. To see clearly the effect of light, put a plant in a box, with a glass window on one side only, so that the light always comes from a single direction. Then it will be easy to see that the plant grows in that direction. These are

FIG. 12.—*Trees at the seaside often grow all to one side, owing to a prevailing wind.*

just examples to show that the development and growth of plants are under the rule of scientific law just like machines made by man. There are plenty of other things which influence plants, of course. Near the sea, trees are often seen growing all to one side. This is due to the fact that in these particular places the wind blows strongly in one direction for much of the time, and influences the way in which the trees develop.

All Living Things come from Seeds or Eggs

The seeds of most plants are small, and many of them blow about easily, so that it sometimes looks at first, to

people who do not know anything about the laws of science, that plants have grown up from nothing. We know, however, that no plant springs up without seed. In the same way it might look at first as if little living things of the animal kind, such as maggots, came of their own accord from nothing in such things as rotten meat. All grubs and such-like come, however, from eggs; maggots only come in meat, first, if the bluebottle or blowfly has laid eggs on it, and, second, if these eggs have had time to hatch out. Sometimes the eggs of insects are laid in other

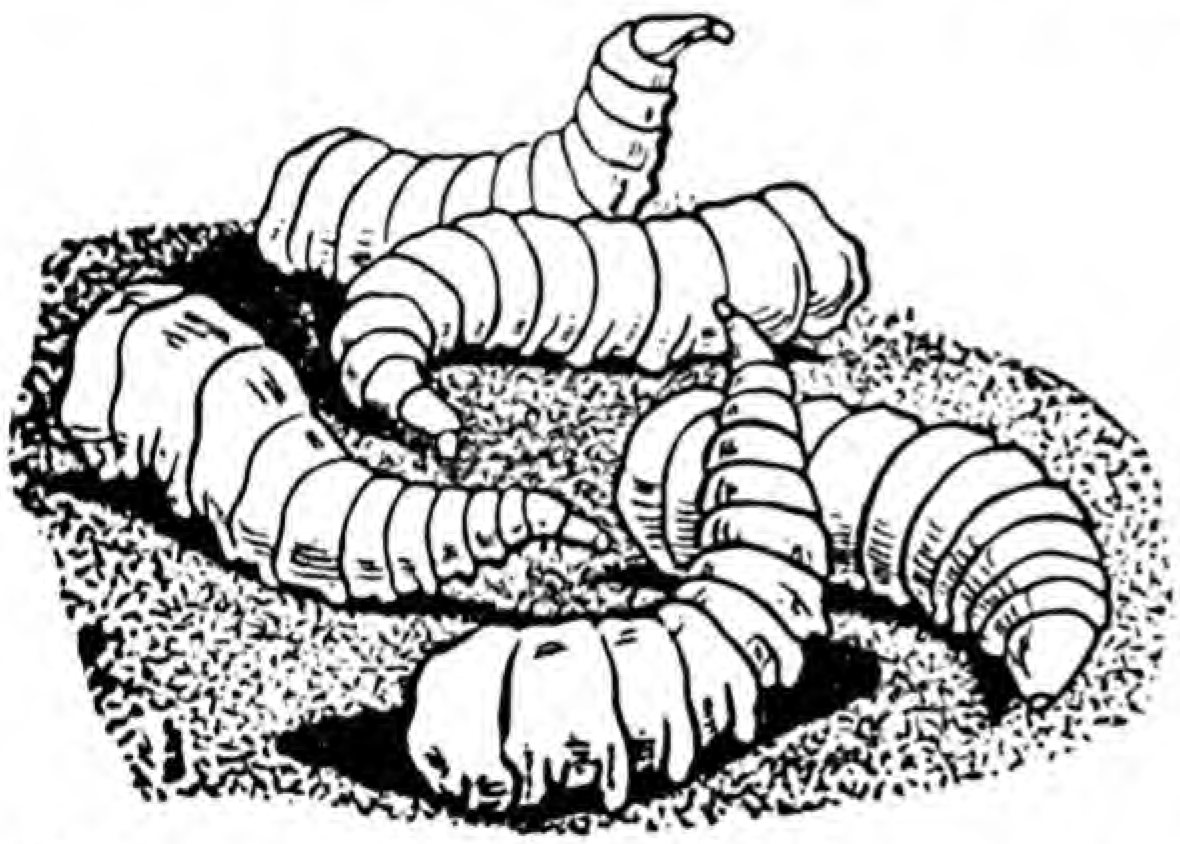


FIG. 13.—*Maggots, which come from eggs laid by bluebottle flies.*

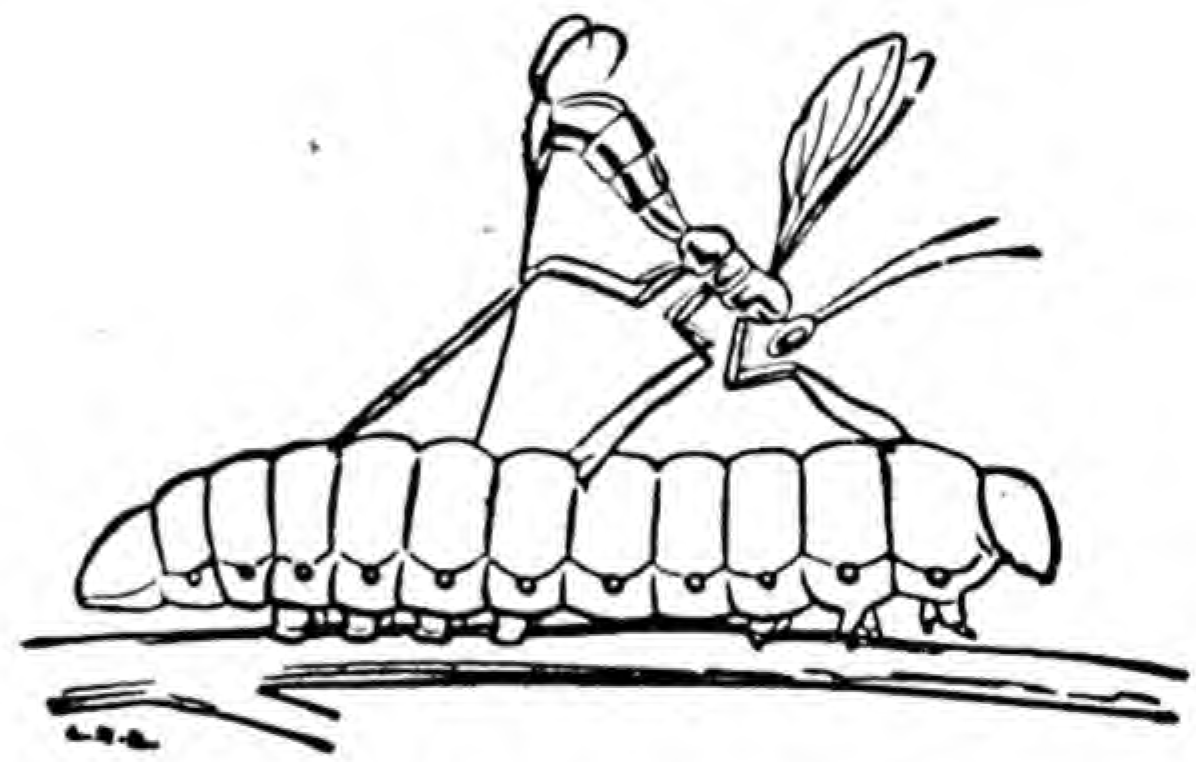


FIG. 14.—*The ichneumon fly laying eggs in the body of a living caterpillar.*

insects, with queer results. Some of the insects called ichneumon flies actually lay their eggs in the body of living caterpillars, and when the eggs hatch out into grubs (which later change to ichneumon flies in a very surprising way) these grubs eat up the meat and juices of the caterpillar until finally nothing but its mere shell is left. The dead caterpillar, with the little white cases, or cocoons, which the grubs spin and in which they undergo their change to grown-up insects, can often be found; and at one time, before it was clearly understood that all insects come from eggs, naturalists thought that the caterpillar

had actually turned into the cocoons which produce ichneumon flies.

Take a little fresh hay, pour some hot water over it, and leave it to stand. In a week or so the water will have grown cloudy, and it will be found to contain hundreds of tiny living things, which are only a few thousandths of an inch across — that is, about ten of them side by side would about reach across a full stop on this page. They are therefore too small to be distinguished for what they are by the naked eye, but they can easily be seen if a drop of the water is placed on a slip of glass and put under a small microscope. The commonest kinds are little egg-shaped creatures covered all over with what look like tiny threads. These beat quickly and act as oars, driving the little animals through the water. These are called cilia, and the creatures are called ciliates, from the Latin word *cilium*, which means an eyelash, for the little waving threads look something like eyelashes.

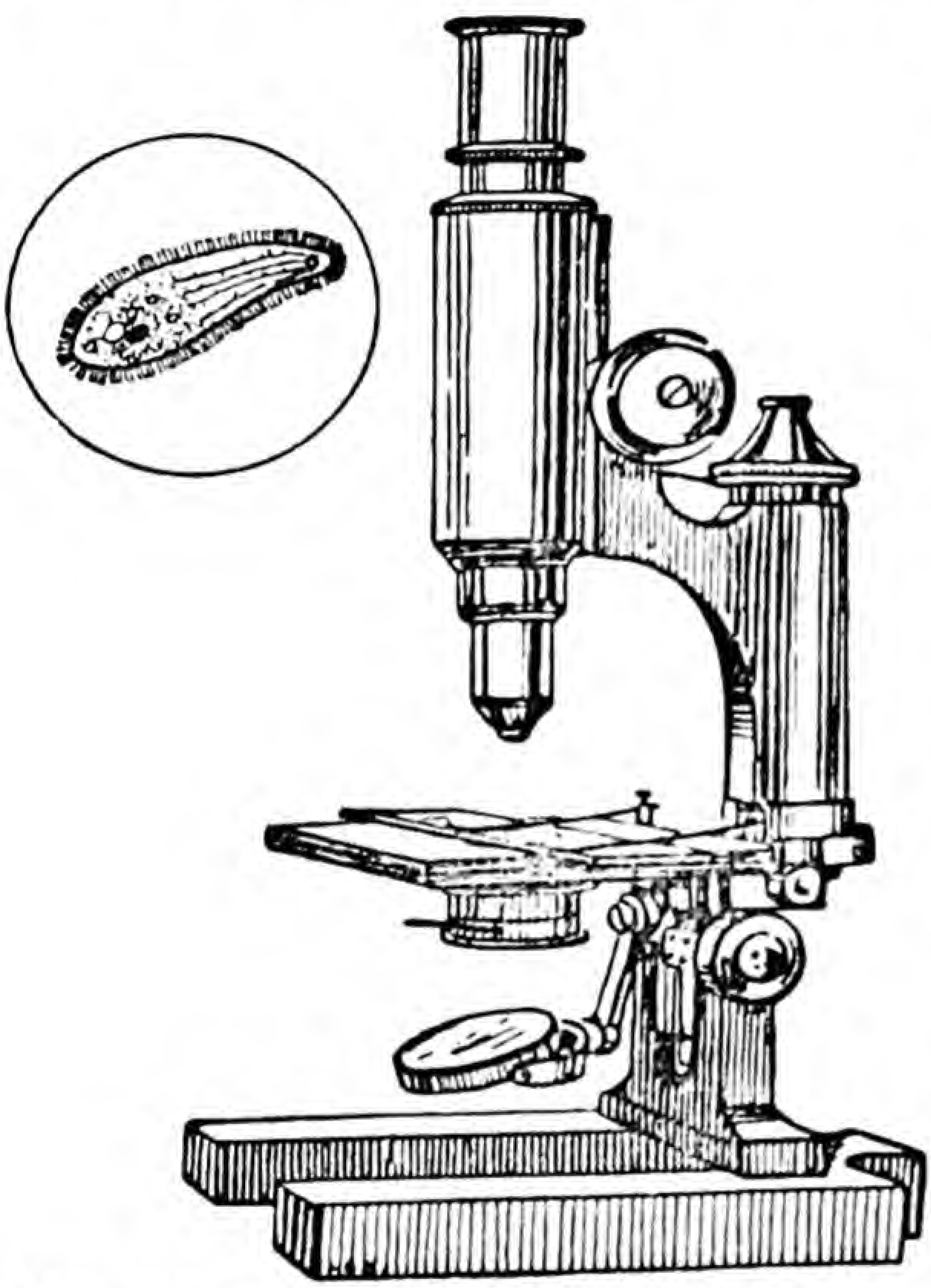


FIG. 15.—*A good microscope, and, in the circle, a ciliate called* Colpoda *as it appears when seen through the microscope.*

When it was first discovered that these animals would appear in water which was left to stand people thought that they just came from nothing, that they just happened

by themselves. About two hundred years after they were first seen men of science found out the truth. These creatures dry up when the water in which they live dries up, and turn into seeds, as it were, with a tough shell, which float about in the air as invisible specks of dust. If one of these falls into water suitable for it to live in, like our hay water, it breaks out of its shell, and begins to swim about. The life in the hay water does not come from nothing, but from seeds which settle out of the air.

We can prove this by taking a little hay water as soon as it is made, boiling it well to kill anything alive or any seeds that may be in it already, and corking it up tight. It will not go cloudy with tiny creatures, but will stay quite clear, with no living things in it, until we open it and let some air get to it. At least it will stay clear if we are very careful with the boiling, which is called sterilising (anything which will not bear fruit or a crop is said to be sterile), and the corking up. It is very easy to let in invisible seeds if we are not careful.

There are things much smaller than the ciliates in hay water, which need great skill and a good microscope to see them. These things are so small that it takes several thousand of them, placed end to end, to make an inch, which means that the length of five or ten of them (for some are larger than others) would amount to the thickness of a cigarette paper. They look like little rods, or worms, and are called germs or bacteria. Bacteria is the plural, and means a lot of bacterium, which is a Greek word for stick or rod: if it were English we should say bacteriums. There are some kinds which, if they get into the blood, cause diseases, each causing its own particular disease. One kind causes consumption, another kind plague,

another kind dysentery, and so on. So we may say that diseases, too, have their seeds, which float about in the air. If they find a weak spot in our bodies they get in and start colonies in our blood, like people in a strange land, and make us ill, but if we keep clean and brisk we can make it more difficult for them to get a start. They are then like seeds that fall on a pavement, and cannot take root. Disinfectants kill them, as certain things kill plant seeds. So we see that diseases have scientific causes, by studying which doctors can do much not only to cure them, but also to prevent them. We can also do much ourselves, by seeing that we do not breathe through our mouths, by taking great care to keep any cut or sore place clean and covered up, by getting fresh air when we can, and by killing flies which go into filthy places and then settle on our food, bringing bacteria with them.

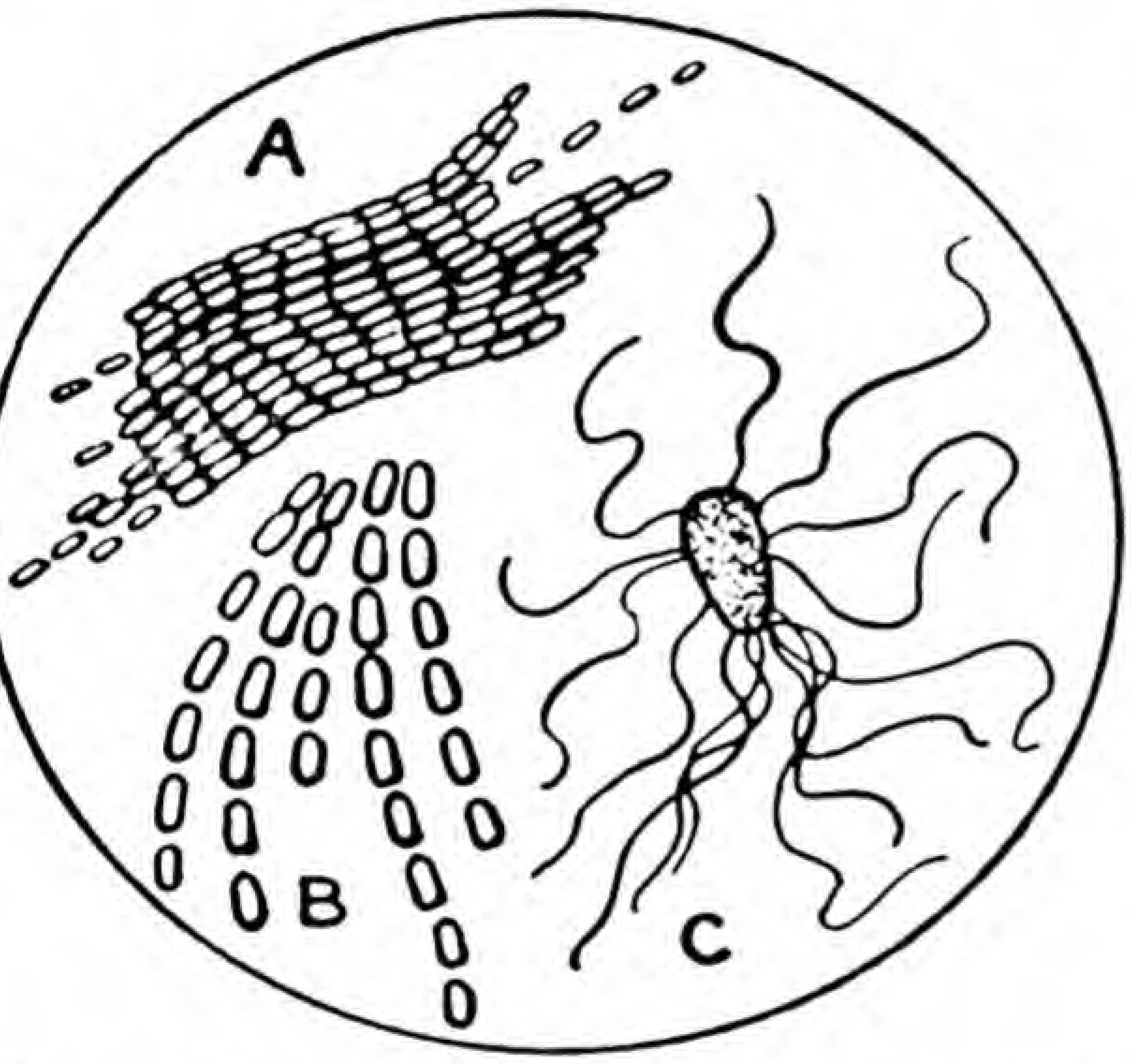


FIG. 16.—*Bacteria. A and B are the kind that make wine turn to vinegar. C is the kind that turn butter rancid.* (*Very highly magnified.*)

We see, then, that living things, such as plants and insects and these tiny microscopic bacteria, all have rules, and all help us to understand what is happening round us. Thus there is a science of living things: we call it *Biology*, and the men who study it, *biologists*. The science of plants alone is called *Botany*, and that of animals is *Zoology*.

Many Things in Animals act like Machines

The closer we look the more we see that things happen according to system, and not just anyhow. Many of the rules of machines and of engineering even apply to living animals. For instance, architects and engineers know that

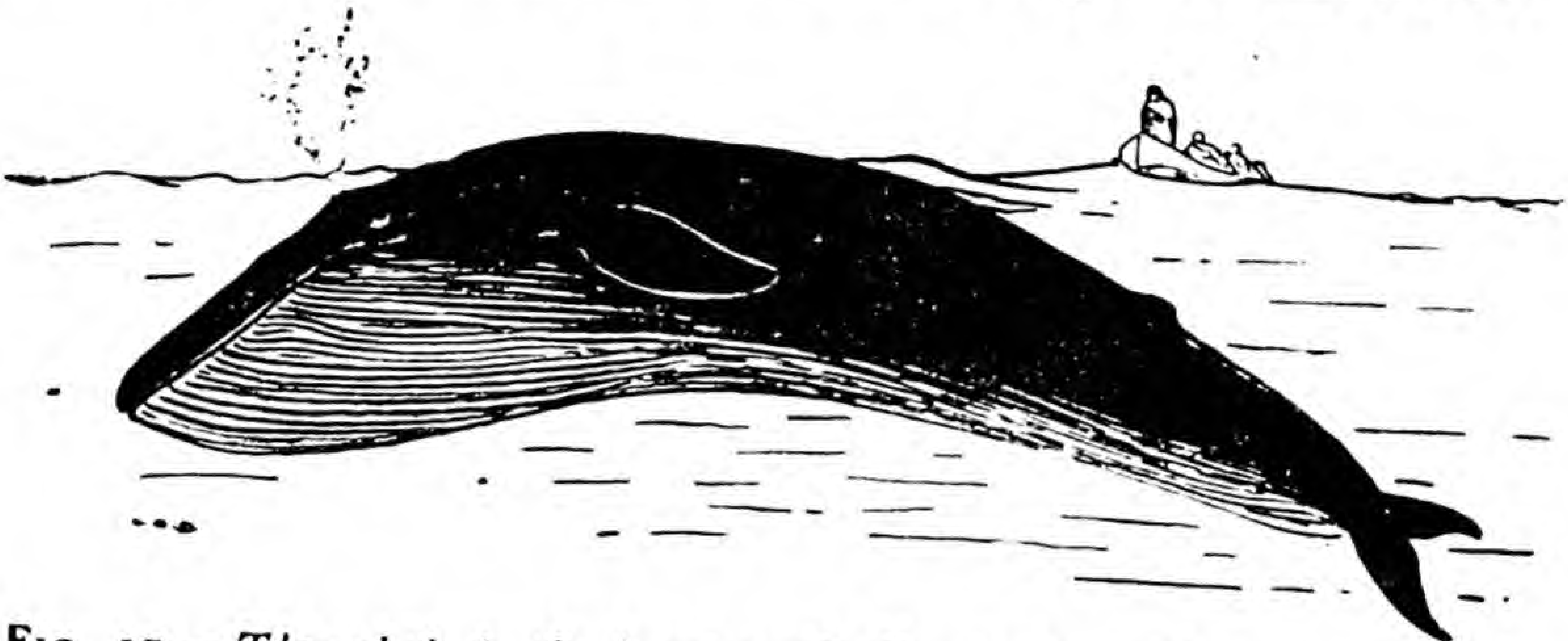


Fig. 17.—*The whale is the heaviest of all animals, and is supported all round by the water. If an animal as heavy as a whale had legs they would have to be so thick that it would be too clumsy to move.*

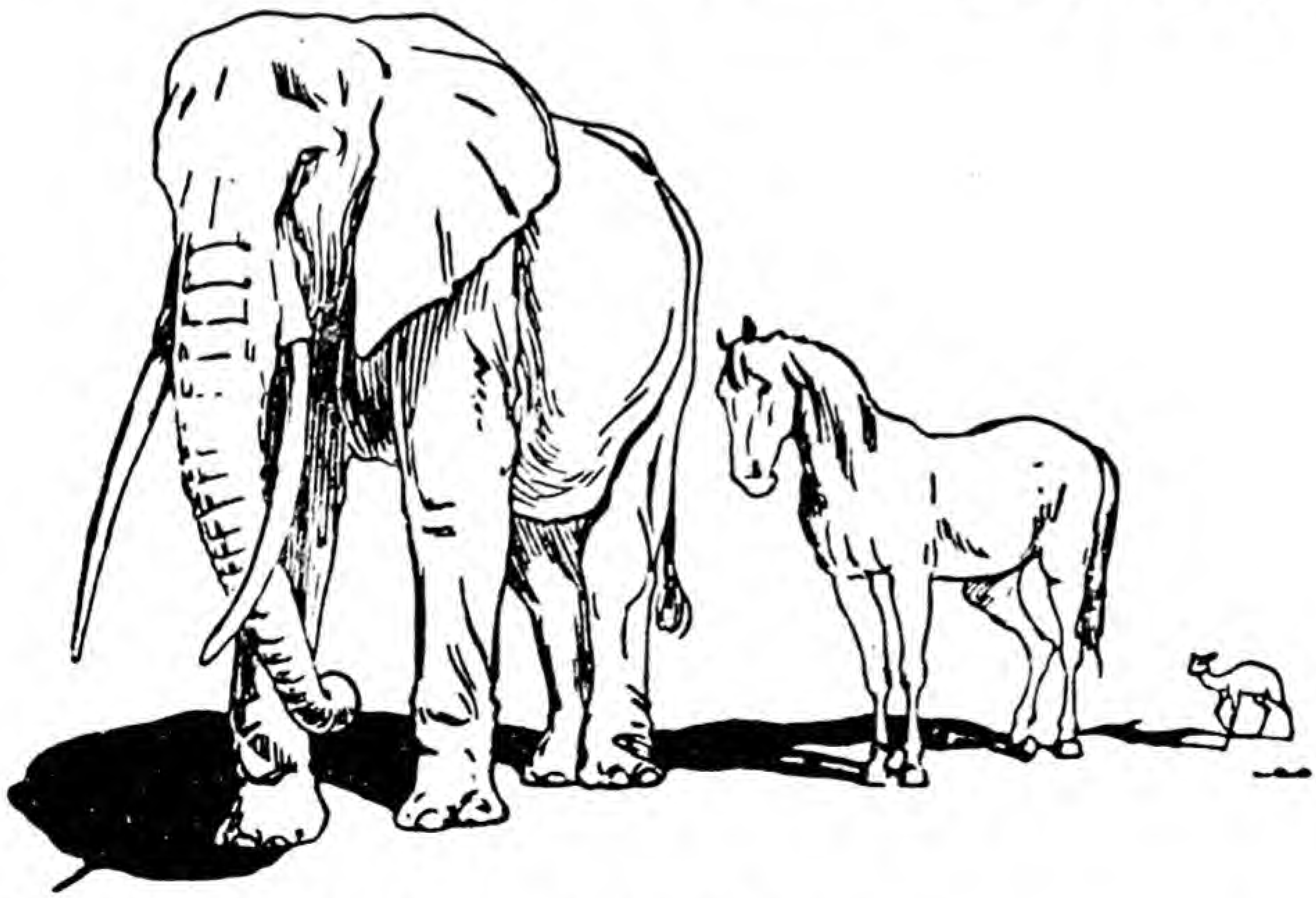


Fig. 18.—*The bigger the animal the thicker its legs must be in proportion An elephant, a horse, and a mouse-deer.*

the larger they build a machine or house the stronger supports does it need, even in proportion to its size. Thus if you look you will see that a real locomotive has much thicker axles, in proportion to its size, than does a toy clockwork locomotive. Now we find this same kind of rule with animals: their supports must be strong enough to hold them up without breaking. The heaviest animal is the whale, which is held up by the water, and does not need legs at all. The heaviest land animal is the elephant, which has very thick legs, even in comparison to

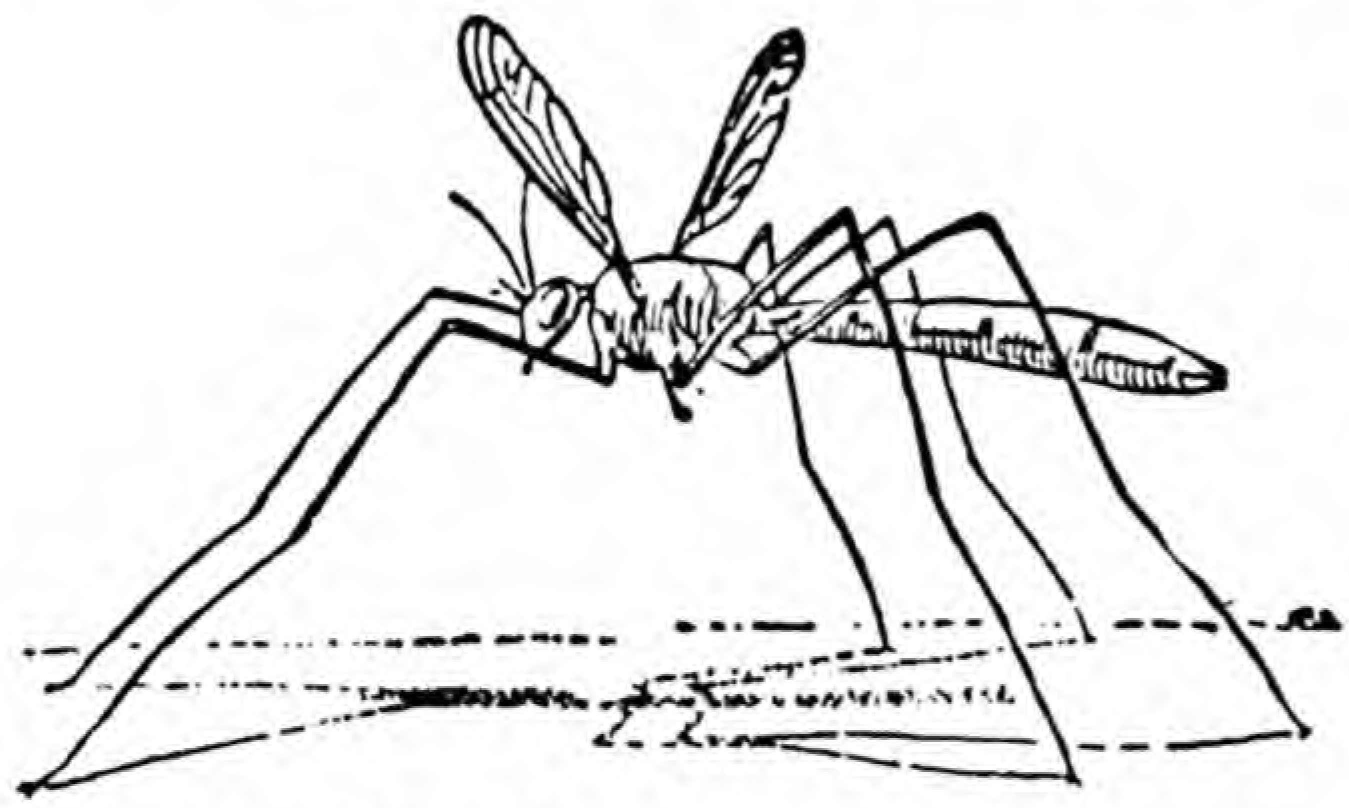


FIG. 19.—*Daddy-long-legs, with very thin legs, even in proportion to its size.*

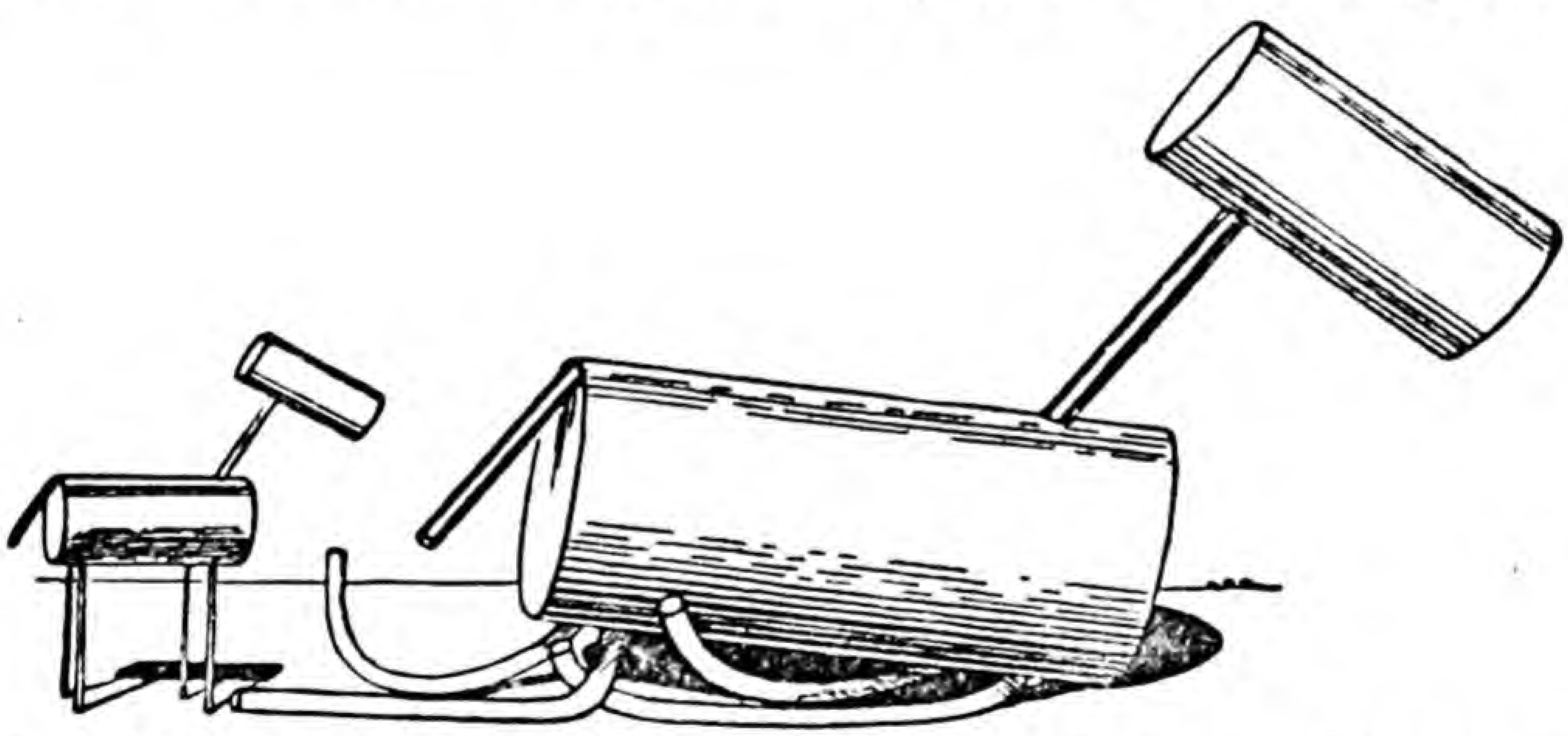


FIG. 20.—*Models made out of lead blocks to show that a small animal can have thin legs; but a large one must be built on a heavier pattern if it is to stand.*

its size. A horse has much thinner legs in proportion, but a light animal like a gazelle has them much thinner still. If a gazelle were made as large as a horse it would risk breaking its legs all the time. The smaller an animal the thinner

its legs can be, in proportion to its size, without failing. Insects like the daddy-long-legs have even thinner legs: a daddy-long-legs a yard across would not walk.

We can make a model to show that big animals require thick legs, by taking two cylinders of lead, one 4 inches long and 2 inches in diameter, and the other just one-third the size each way, that is $1\frac{1}{3}$ inches long and $\frac{2}{3}$ inch in diameter. It will be found that the small block will stand comfortably on four legs of lead wire each $\frac{1}{25}$ inch in diameter, but that four legs of lead wire just three times as thick collapse under the large block. The reason is that only the width and breadth of leg help to hold up the block, the extra length being no help, but the extra height of the block adds to the weight, as well as the extra width and breadth. The big block weighs $3 \times 3 \times 3 = 27$ times as much as the smaller block, but the legs are only $3 \times 3 = 9$ times as great in area of cross section. In Fig. 20 you see the two lead blocks, with the legs collapsed under the larger one: in Fig. 18 you see various animals, to remind you that the smaller the animal the thinner in proportion can be the legs which are strong enough to hold it up.

So you see that animals are built on a plan. They are, in fact, a good deal like buildings and a good deal like machines. The skeleton of an animal is like the steel frame which they build for a large building nowadays, and afterwards cover over by the walls; you cannot see, it but it supports the building and holds it together. Our arms and legs act like levers; our heart acts like a pump, pumping blood instead of water; our nerves act like telephone wires transmitting messages; our stomach, into which food goes, is something like a factory, which turns food into stuff which our body can use, just as a factory turns rough iron and wood into things which are useful.

What a lot of things there are for us to study. Science, which tries to find out the way in which all things, living and not living, work, helps us by means of this knowledge to do things better and more efficiently. It helps us to make engines and all kinds of machines, which add to our comfort and lessen the labour required to manufacture things, so that they become cheaper: think of steam engines, cheap printing machines, cold storage of food, and electric light. It helps us to grow crops: think of improved seeds, and cheap artificial manures. It keeps our cities healthy, and fights disease: think of disinfectants and X-rays. It looks after the safety of our sailors at sea: think of wireless telegraphy. But, quite apart from all these things of practical use, it makes things much more interesting for us if we can get some little idea of the reason for puzzling happenings, and can account for some of the wonderful ways of things which we may notice if we keep our eyes open. The boy or girl who knows nothing of science is like someone on a steamboat who just sits on deck, and goes to sleep between meals. The boy or girl who knows something of science is like someone who has had a look round the engine-room, understands how the compass is read, and has found out a little about the steering wheel and the rudder. He or she knows something of the way in which the whole ship is driven and guided to her destination, and has something to make the whole voyage interesting. Of course the wise traveller will also enjoy the waves and the wind and the starlit skies at night, and that reminds us that there are other things in life than science, and then the best of all is to be interested in everything, and notice all we can, beautiful things and useful things and human and moral things together.

CHAPTER II

THE NATURE OF THINGS

The Importance of Observing Carefully

WE will now see what we can learn about some of the things around us, by examining them a little more carefully than people often do. One of the chief things in science is careful observation, for things that look rather alike may actually be very different when we come to look closely. There is a story of a professor of medicine who was giving his first lesson to young men who were going to be doctors. He said to them that if they wanted to become good doctors there were two things most important for them: one was to observe well and carefully, and the other was not to be disgusted at unpleasant things. In front of him was a bowl of dirty dishwater, with an offensive smell, and he went on to say that, to test them, he was going to put a finger first in the water and then in his mouth, and that he wanted them all to do after him exactly what he did. Accordingly, he dipped in a finger, and then put a finger in his mouth. In spite of the unpleasantness of the water, the students came up one by one, and put a finger in the water and then in the mouth, bearing the very unpleasant taste as best they could. At the end of it all the professor said: "I must congratulate you, gentlemen, on all having one of the qualities necessary, but one alone. You do not let horrible things disgust you, but neither, unfortunately, do you observe carefully, or you would have noticed that, whereas

I put my second finger in the water, it was the third finger that I put in my mouth." Let this story serve to remind us of the importance of noticing what really happens, and not what we think is going to happen.

Smoke and Steam

We may now consider two things of which people often talk as if they were much the same—namely, smoke and steam. Both often form little white clouds in the air, both can be seen coming from a locomotive engine, or other steam engine, but they are quite different things. Steam

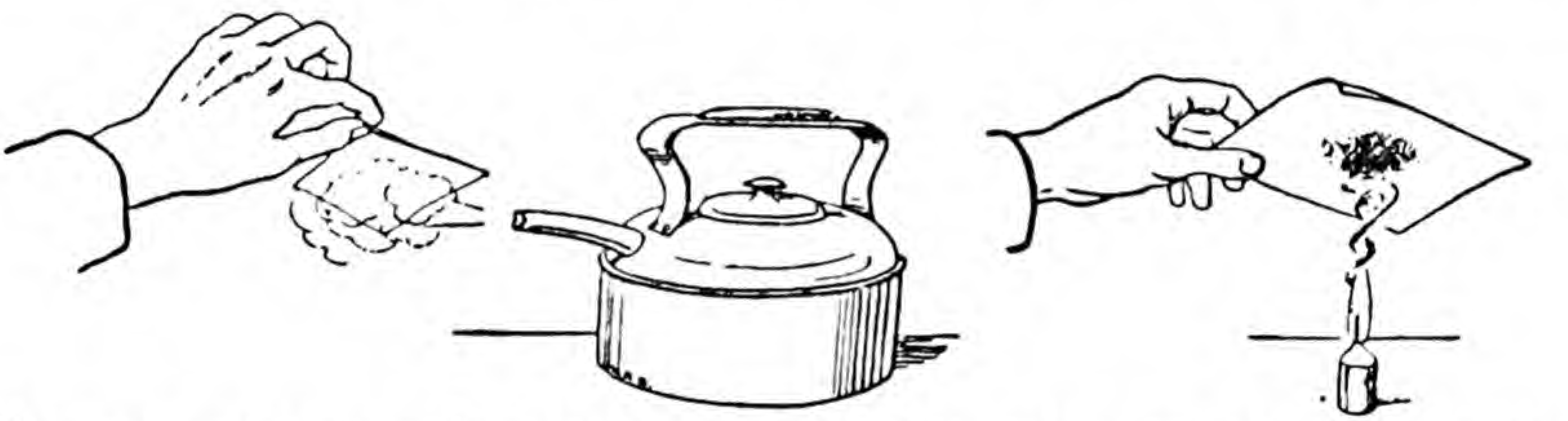


Fig. 21.—*Steam makes paper wet and leaves it clean; smoke blackens paper and leaves it dry.*

comes from boiling water; smoke comes from fuel, such as coal or wood or oil, burning. Let us do one or two little experiments to see the difference. Hold a piece of paper in the steam coming from a kettle. It gets wet, but stays clean. Now hold a piece of white paper in the smoke from a piece of burning wood, or from a candle, or from an oil lamp, taking care not to bring it close enough to catch fire. The paper keeps dry, but gets dirty. Steam is wet and clean, smoke is dry and dirty. The grey cloud of steam is all made up of tiny drops of water, the cloud of smoke is made up of tiny particles of soot, or carbon as the chemists call it. Coke and charcoal are also carbon,

but in a hard form. You might say that soot is soft coke.

We notice another thing about smoke. Smoke comes from bright flames, like the yellow flame of a candle or a burning torch, or a newly lit coal fire. It does not come from the faint blue, nearly colourless flame of the gas-stove burner, nor from the pale flame of the methylated spirit lamp, nor from the glowing fire when it has settled down without flame. If we put a little finely powdered soot on a glowing coal, or put it in a little fireproof porcelain pot, called a crucible, and heat the pot strongly in a gas flame, the soot burns away. If we sprinkle a little soot through the flame of the spirit lamp we see bright patches in the flame for a moment. We can now guess the secret of smoke. The bright flames are bright because they contain tiny particles of unburnt soot, or carbon as we now call it, which comes from the burning stuff, for coal and wood and candle-grease all contain carbon, as we learn in the study of chemistry. The tiny pieces of unburnt carbon, which glow gaily in the flame and give out light, pass out of the flame still unburnt and then settle down on anything held near the flame, or, if there is nothing there, pass out into the air and clot together to make the larger particles which we see as smoke.

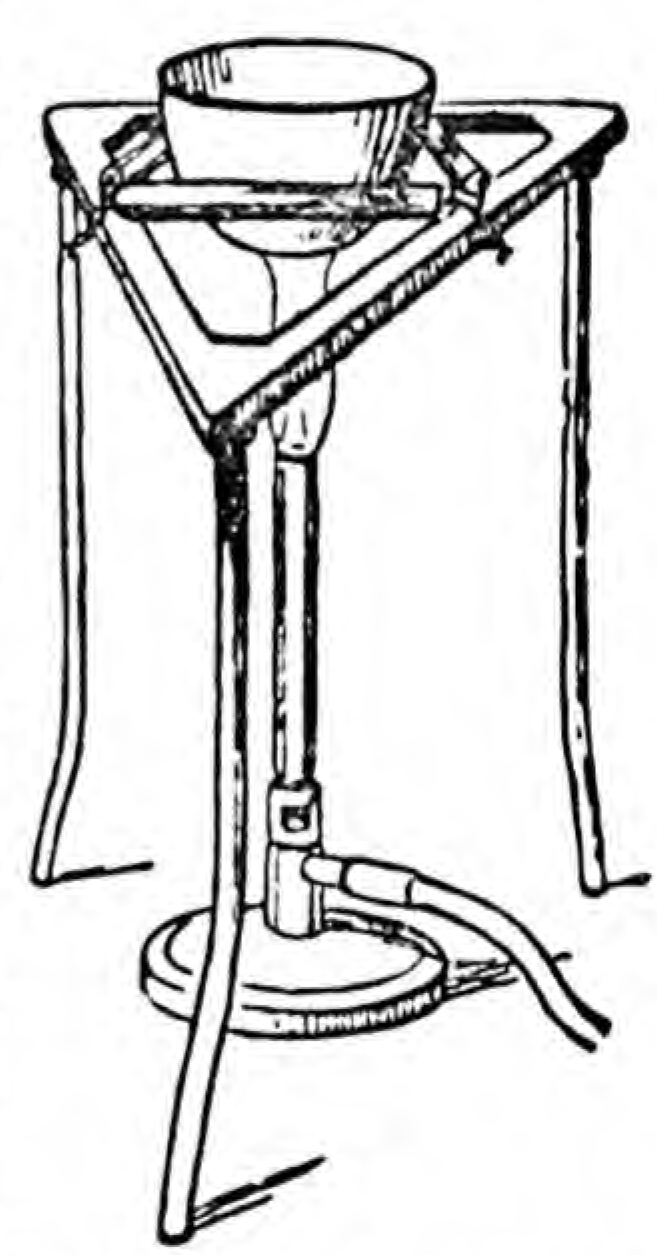


FIG. 22.—*Soot heated strongly burns away.*

In a colourless flame, like the gas flame supplied with plenty of air, such as we have on a gas stove, all the carbon is burnt up, and we have no brightness and no soot. Whether the carbon is all burnt up or not often depends

on the air supply. If the holes in the pipe through which extra air gets into the gas on the gas stove are stopped up, the flame will become bright. This can be shown with a gas burner of the kind called a Bunsen burner, after the German Professor Bunsen who invented it. The burner has holes, like the gas-stove burner (which was copied from it), through which air can get into the flame with the gas, so that there is air both inside and outside the flames. If the holes are open the flame is pale and not smoky: if the holes are closed the flame is bright and smoky. If there is no gas, the same thing can be shown with a candle. Take a little blowpipe, of the shape drawn in the picture, and blow into the candle flame, as shown. The long flame which comes out of the side is clear, hot and not smoky. The air blown in has helped the carbon to burn away.

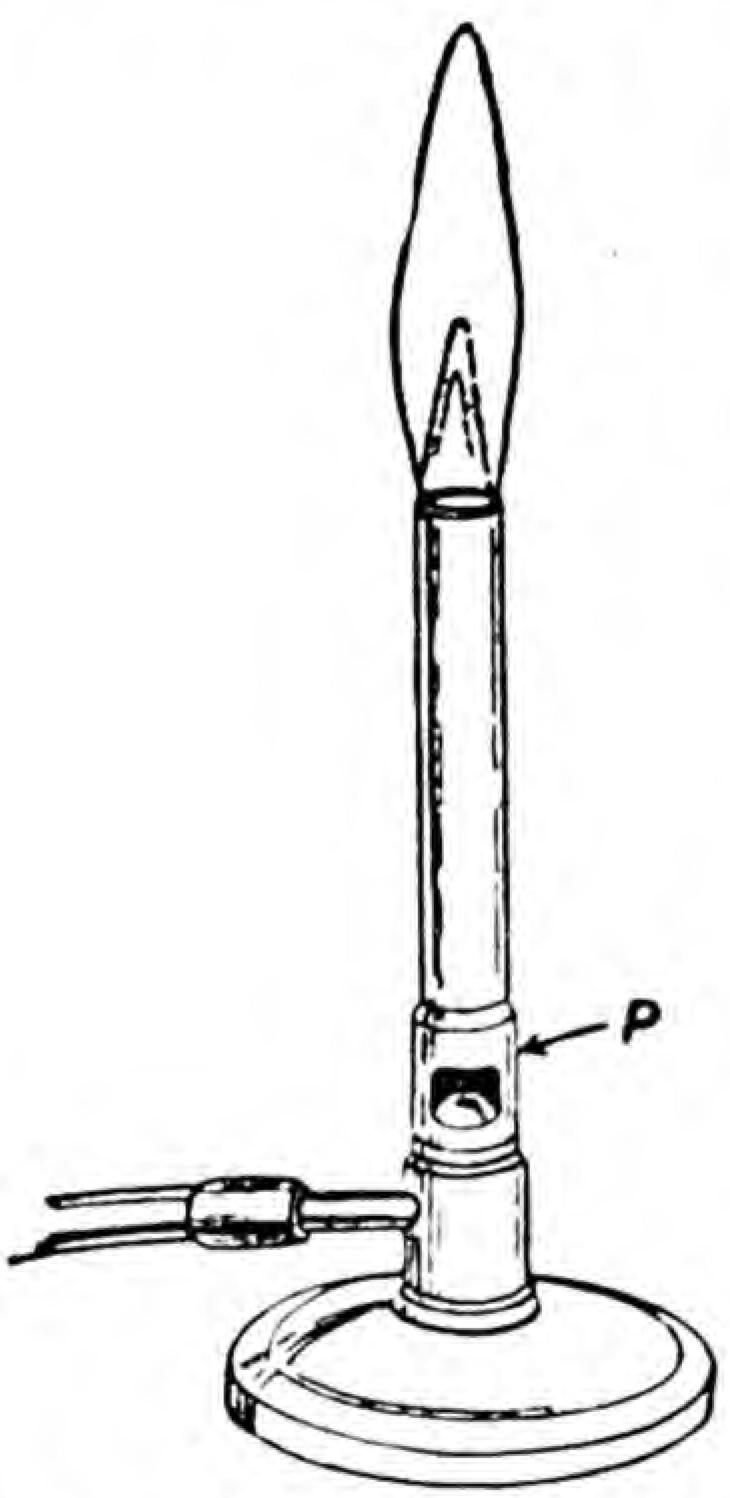


FIG. 23.—*The Bunsen burner. The holes can be closed by turning the piece P.*

FIG. 24.—*Melting an iron wire in the hot blue flame produced by blowing into a candle flame with a blowpipe.*

More about Steam

Now that we know something about smoke, let us go back to steam, and look at the kettle spout more carefully. When the kettle is boiling vigorously we see, between the end of the spout and the beginning of the steam cloud, a clear space. There seems to be nothing there. If, however, we put a clean cold spoon close to the spout we find it at once becomes covered with drops of water. What happens is that when the water is boiling away it is becoming something which, like air, cannot be seen. This something is actually the same stuff as ordinary liquid water, turned into a thin and invisible form. We must beware of thinking that, if we can see nothing, there is nothing there. We cannot see the wind, but we can feel from its rush against our face that it is there. The wind is, of course, air moving, and nothing else. There is something invisible rushing out of the spout of the kettle, but it is not air.

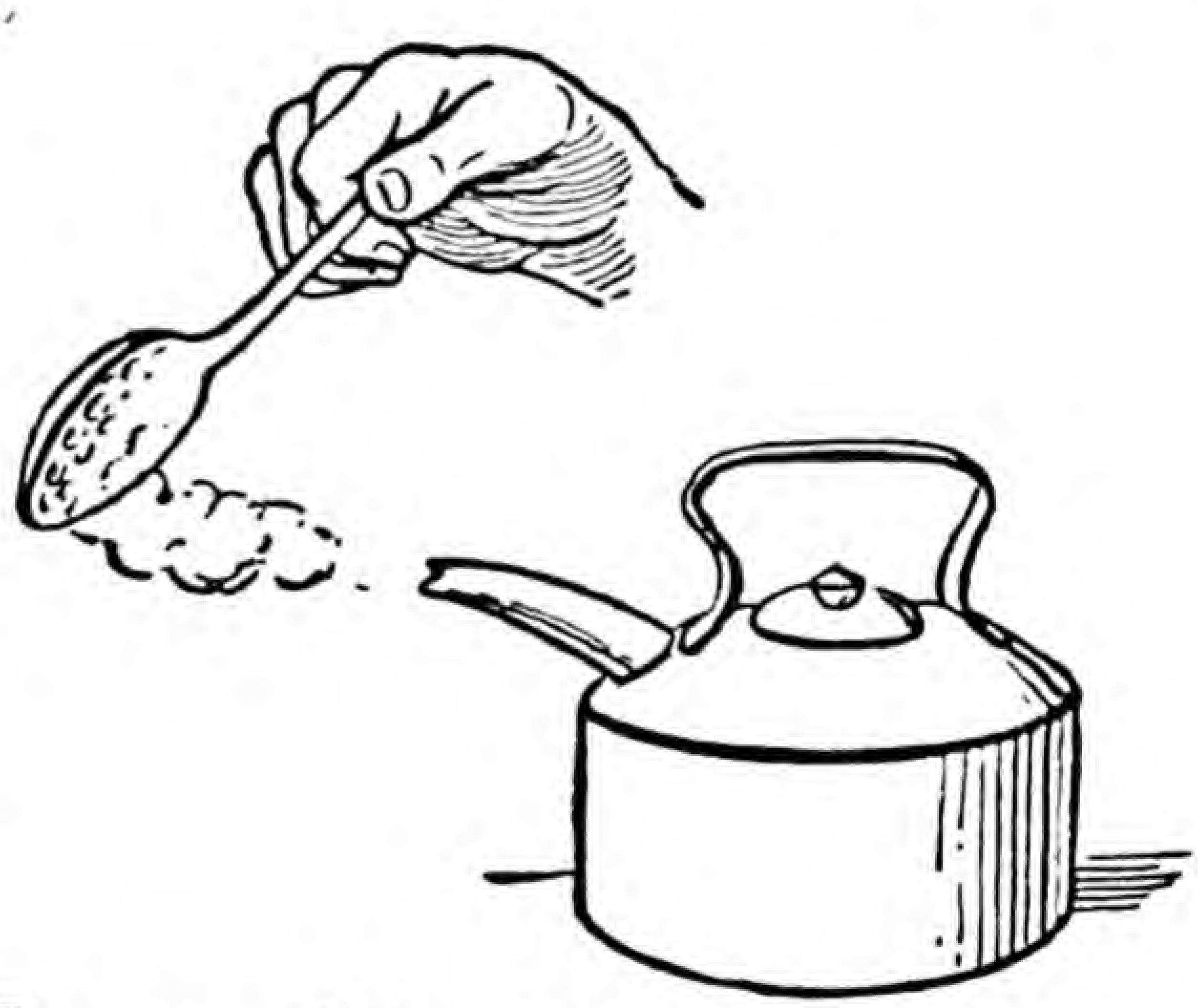


Fig. 25.—*Steam is invisible just where it leaves the spout of the kettle, and turns to water on the cold spoon, even when the spoon is put close up to the spout, just as it does when the spoon is further off, as in the picture.*

This invisible water-stuff is the real steam. As soon as it gets a little way from the spout it cools down and turns back into water, first of all into tiny drops of very hot water which hang in the air and form the cloud which is generally called steam. The cloud of drops is, however, merely water broken up fine, just as a stone might be

powdered and blown about as a cloud of dust. The drops are formed from the invisible steam, which made the drops on our cold spoon held close to the spout. We may say, then, that water, when boiled, turns into a special kind of airy substance, called steam, which turns back into water when it cools.

The clouds, which we see in the sky, are really masses of very tiny water drops, just like our cloud near the boiling kettle. Very small things fall very slowly, because the air hinders them. You can see this by shaking a chalky duster; the little bits of chalk which form the dust settle quite slowly and do not fall like stones or other large and heavy things, which are not much hampered by the air. The clouds, therefore, being made up of exceedingly small drops, settle down only very slowly, but they are falling slightly all the time. In flat parts of England they always turn to large drops which fall as rain long before they reach the ground, but in mountainous parts it is quite common to see the clouds beneath one, and aeroplanes often fly above the clouds. The highest clouds are about five or six miles above the ground, and the low clouds a mile up or so, although they often come lower. Fog or mist is a layer of cloud formed actually on the surface of

FIG. 26.—*Clouds can often be seen below mountain peaks, and aeroplanes often fly over clouds.*

the land or sea, and moving slowly over it. Near or in a town the tiny drops of water are often very dirty from the smoke, and form a cloud through which very little light comes, so that, in London particularly, fogs sometimes occur which make it necessary to light the street lamps at midday. Fog and mist are both the same kind of thing; fogs are thicker and darker clouds, while mists are thinner and whiter.

The Airy Stuffs called Gases

Clouds and the cloud-like puffs that come from the kettle, or the steam engine, or from the moist breath on a cold day are, then, merely millions of little tiny drops of ordinary liquid water. But we have seen that the real steam, close to the end of the spout, is, like air, invisible: it is a kind of air, but not ordinary air, for it turns into water. There are other kinds of invisible airy stuffs. Soda-water and many other bottled drinks are full of bubbles, but the bubbles are not ordinary air, as we can easily show. We can collect them in the following way. We fill a flask with soda-water and cork it tight with a cork through which a curved tube passes, as in the picture. The end of this tube dips into a basin, and we hold over it near the end a long glass jar upside down and quite full of water. We

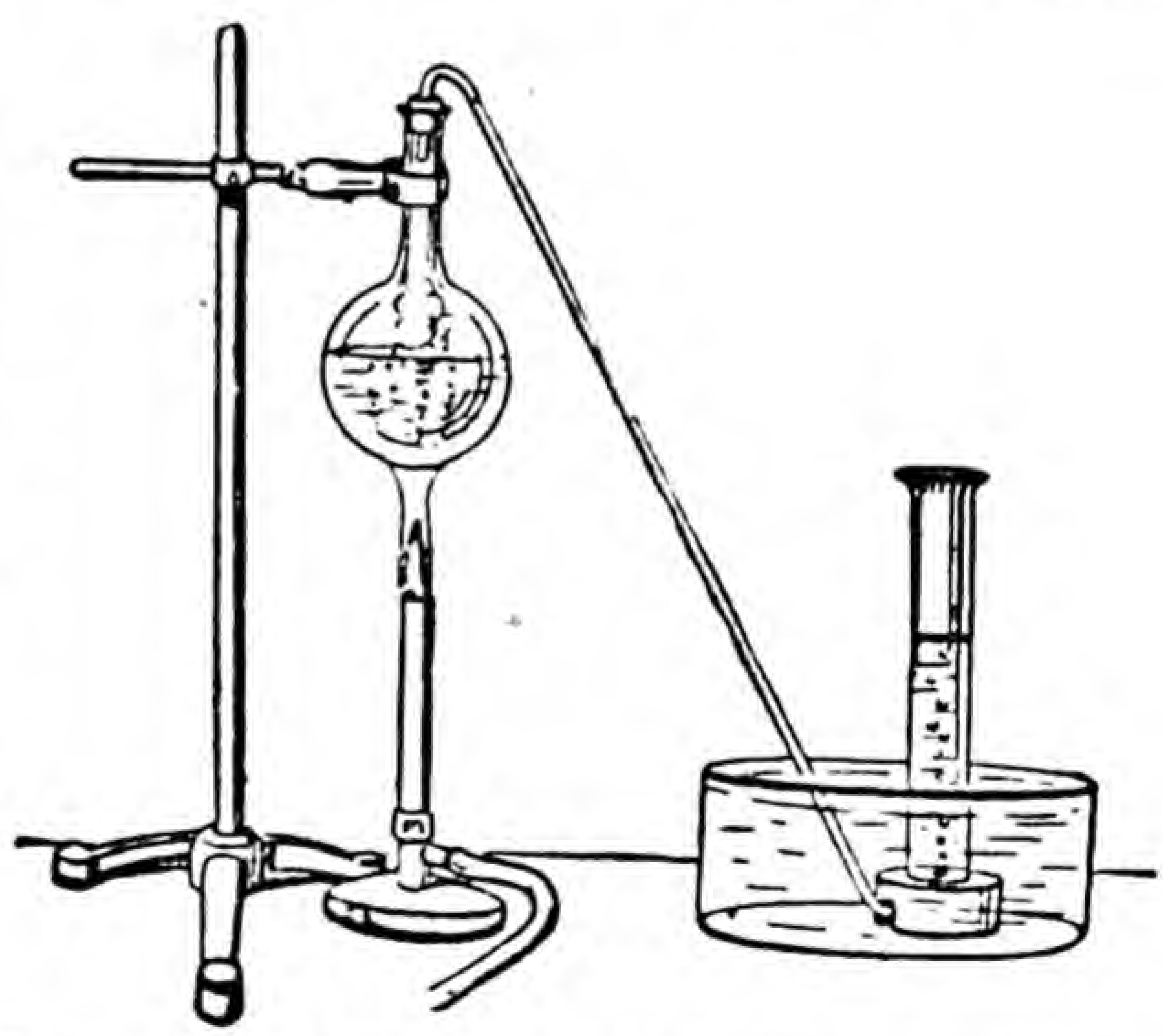


Fig. 27.—*Collecting the bubbles from soda-water.*

now gently heat the soda-water to make the bubbles come off freely, and, after letting the first rush escape through the water, so as to push out any ordinary air in the top part of the flask and the long tube, we hold the glass jar over the end and catch the bubbles in it: they push out the water as they rise. When we have the jar full of bubbles, we cover the end with a glass plate and lift the jar out of the water. We raise the plate for an instant, slip in a well-lighted match—best of all a wax match which burns well—and put the plate back. The match goes out at once. We now do the same thing with another jar full of ordinary air. The match goes on burning for some little time. The kind of air from soda-water is not therefore ordinary air, for things cannot burn in it.

Another way of showing this is to let the bubbles that come out of the tube from the soda-water bubble through a clear liquid called lime-water. It at once turns milky. Ordinary air does not turn lime-water milky, as we can show by taking a football pump, and pumping through a piece of rubber tube into the lime-water. It stays clear. But if we blow down the rubber tube into the clear lime-water it turns milky. This shows that the air which we breathe out is not the same as the air we breathe in, but has some airy substance mixed with it which is of the same kind as the bubbles from soda-water.

Another way to get the soda-water-bubble-air, which scientific people call carbon dioxide, is to put some pieces of marble in a flask with a certain kind of acid. Bubbles will begin to form at once, and if we close the flask with the cork with the long bent tube we can collect them in the jar as before, and show that a match will not burn in the jar. This is, in fact, the way that soda-water is made: the bubbles from marble and acid are collected and pumpedinto strong

steel bottles, and then afterwards let escape from the steel bottles into the water, or lemonade, or whatever drink is to be made bubbly. You can buy the steel bottles full of carbon dioxide at certain shops (see Picture 78 in Chapter V).

We get bubbles of airy stuff when acid is put on other things besides marble. For instance, we can take some pieces of zinc and pour sulphuric acid on to them, and then collect what comes off with our bent tube and glass jar, always taking care not to collect the first bubbles, which will be mixed with the ordinary air that was in the flask to begin with. This kind of air from zinc and sulphuric acid is quite different from that from marble and acid. If we put a match near the end of the jar, where it is mixed with ordinary air, there will be a loud pop. It is best to use a small jar for this. Or, waiting for five minutes so that we are quite sure that all the ordinary air has been pushed out by bubbles from the zinc, we can light the stuff coming out of the tube just as if it was the kind of gas from a gas stove. It will burn with a bluish flame.

We see, then, that there are different invisible airy stuffs which stream about freely like ordinary air, but are in some ways different from ordinary air. In science we call all these stuffs *gases*. Lighting gas is only one kind of gas: steam, before it turns into drops of water, is another: carbon dioxide is another: the gas from zinc and sulphuric acid, which is called hydrogen, is another. Lighting gas is actually a mixture of different kinds of gases, and has a lot of hydrogen in it. After all, it is not surprising that there should be different kinds of stuff like air, for there are plenty of different kinds of liquids besides water.

The Behaviour of Gases

Gases are different from liquids in many ways: they are, for instance, much lighter and thinner, so that we can put our finger through them without feeling anything. They will not stay in a basin, but stream about and mix with the air unless we keep them sealed up. The liquid called ammonia is really a gas called ammonia dissolved in water. If we unstopper the bottle we can soon tell by the smell that the ammonia gas has moved out and found its way all over the room. Some gases have a smell, others have not. All gases are not colourless, like air and hydrogen and carbon dioxide and ammonia. If we pour some nitric acid on copper, beautiful red fumes come off, which are a visible gas, called nitrogen dioxide. It is thin and streaming, so it is a gas.

Gases are very interesting, although most of them can be neither seen nor smelt. Some are lighter than air,

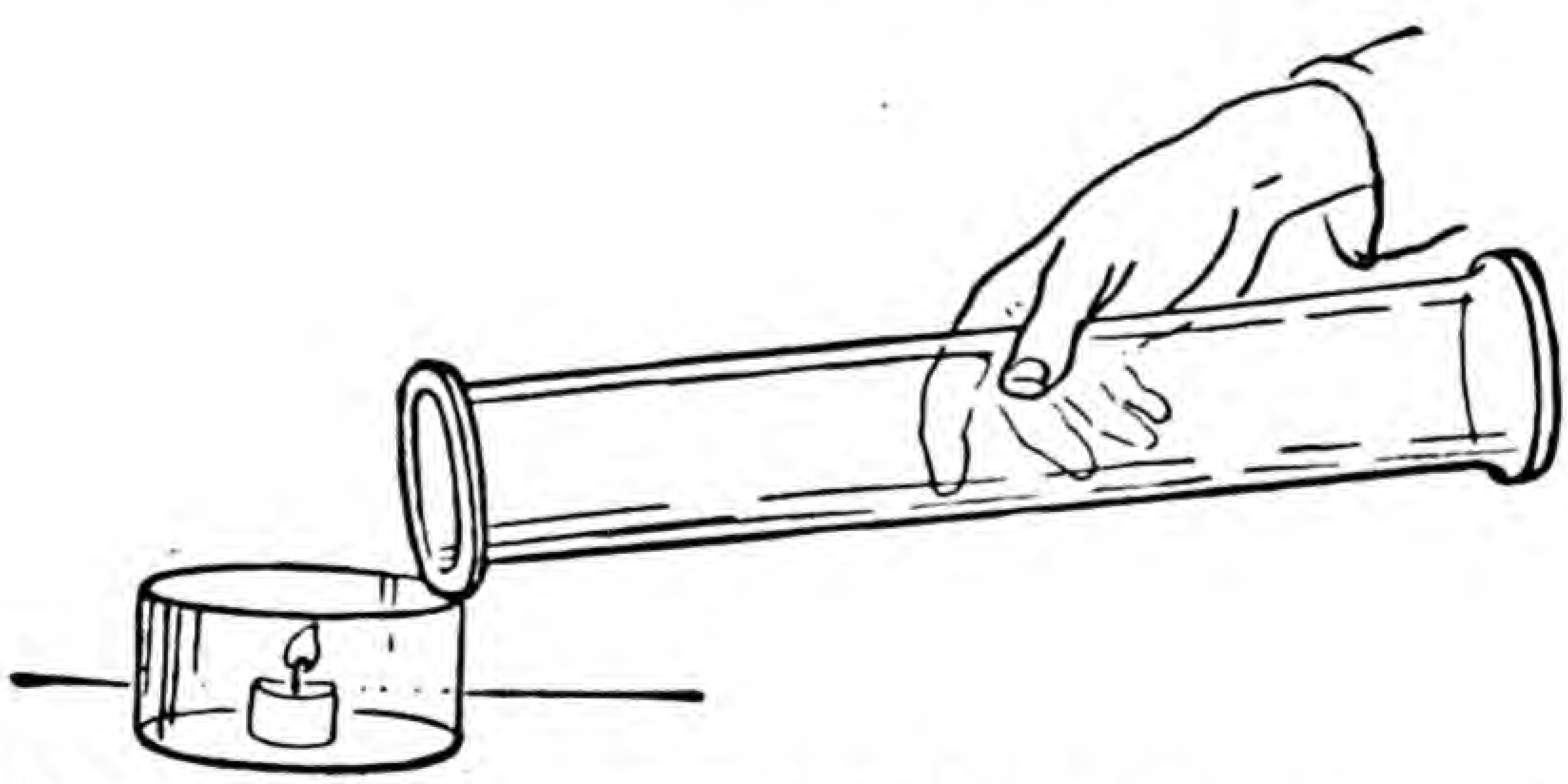


Fig. 28.—*Putting out a night-light by pouring the invisible ga, carbon dioxide on to it.*

others are heavier. Carbon dioxide is heavier. If we have a little night-light burning we can put it out by slowly pouring the carbon dioxide, which we cannot see, from the jar in which we have collected it. It falls down from

the jar, like a stone into water. Hydrogen, on the other hand, is lighter than air, and rises like a cork released at the bottom of a bath. If we squeeze out a thin balloon, which is best if made of collodion, as rubber is usually made too thick and heavy, and then fill it with hydrogen from the tube of the zinc and sulphuric acid flask, it will float up. This is, in fact, how balloons and big airships are made to float. They are filled from great steel bottles into which hydrogen has been forced with strong pumps. There is another gas which is twice as heavy as hydrogen, but still much lighter than air, called helium, which has the great advantage that it does not burn in air, as hydrogen does, and so is much safer. An airship was filled with it in America, but it is so difficult to get that hydrogen is generally used to-day. People are not allowed to smoke in an airship for fear of a leak of the hydrogen from the inside of the enormous gas bags into the air. If this happened, any light or spark would cause a terrible explosion of the mixed hydrogen and air, of the same kind that takes place if a light is brought near a mixture of ordinary lighting gas and air. The explosion would be followed by a fire.

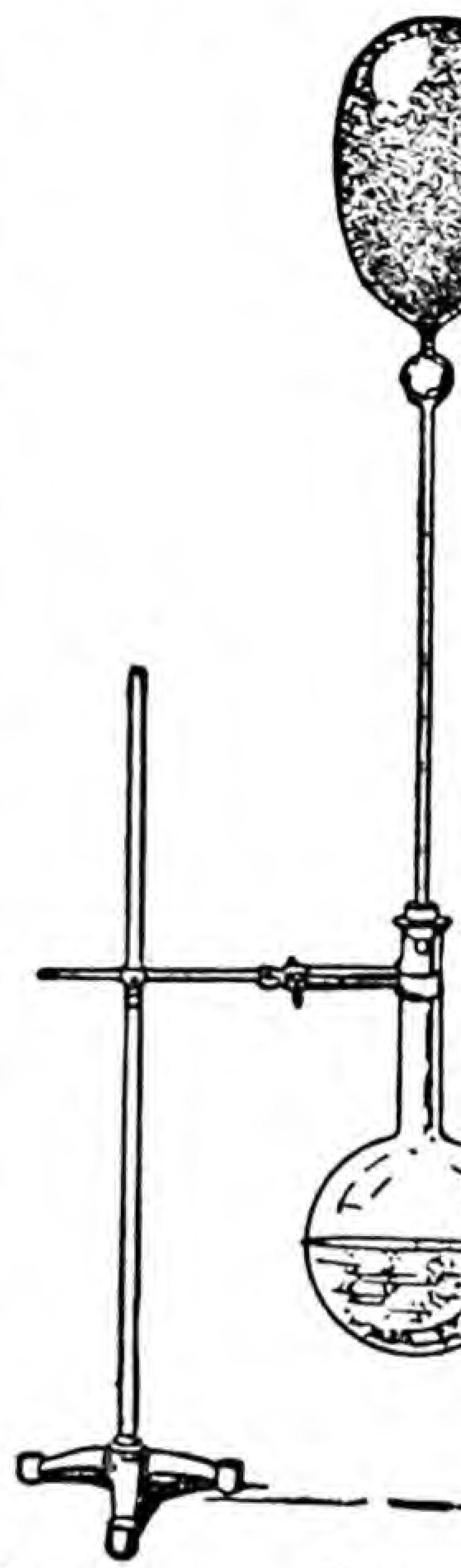


FIG. 29. — *Filling a balloon with hydrogen. The balloon, made of thin collodion, is best filled through a tall straight tube, furnished with a small bulb in which a little cotton-wool is put. This prevents spray from the flask getting into the balloon. When the balloon is full it is tied and taken off the tube. On release it will float up rapidly.*

We now have some idea of what men

of science mean by a gas. Everything that has weight is either a gas or a liquid or a solid. We have talked about gases first because they are not so much noticed in ordinary life as liquids and solids, and so require more explanation.

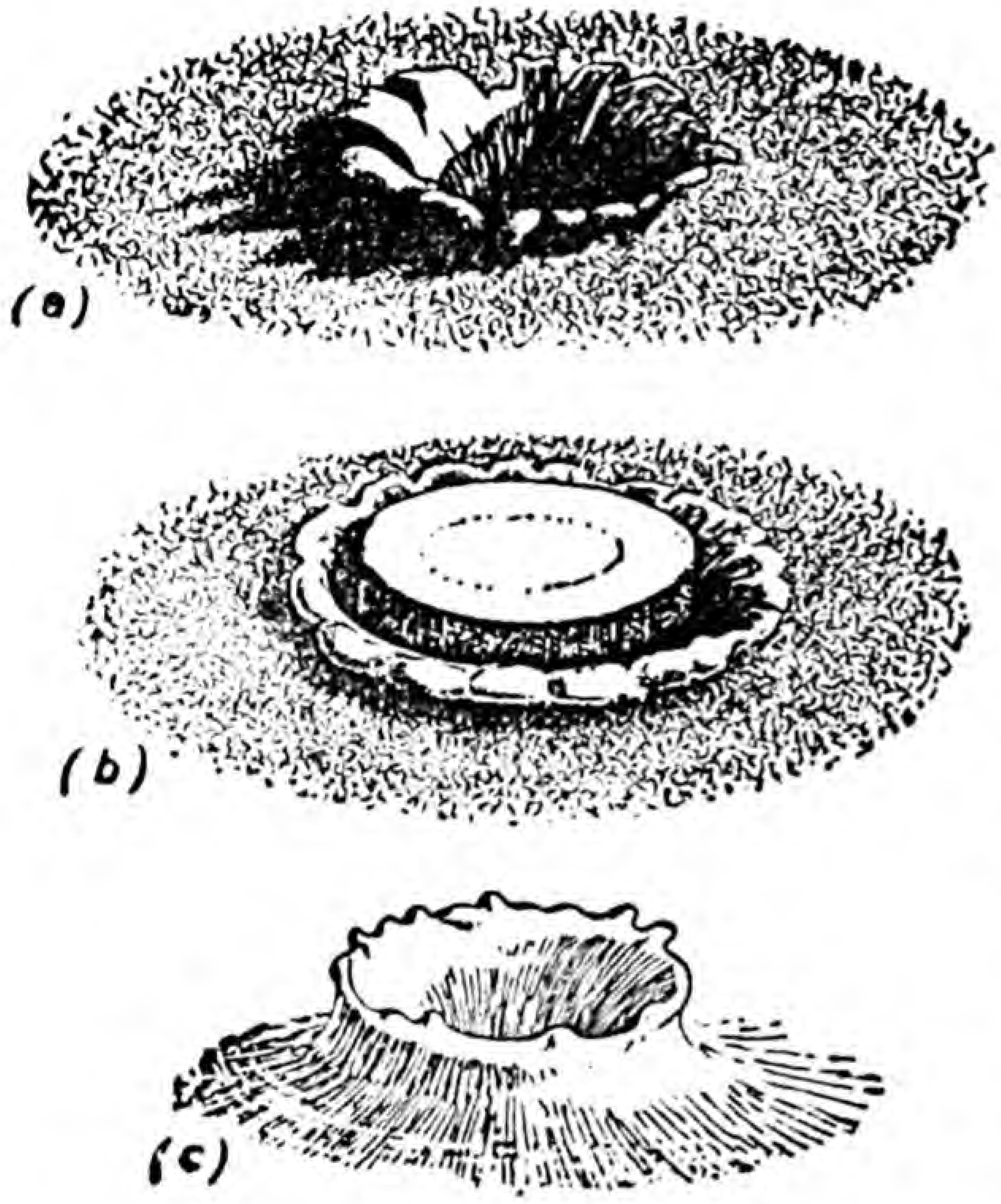


FIG. 30.

(*a*) *The hole in a steel plate caused by an armour-piercing shell which has gone right through.*

(*b*) *The hole in a steel plate in which is seen the base of a shell which has not gone quite through.*

(*c*) *The splash caused by a drop of water falling into water.*

Everybody knows the difference between a solid and a liquid. The thing that strikes you at once is that anything solid, such as a stone or a piece of metal or wood, has a shape of its own, while a liquid like water takes the shape of any vessel into which it is poured. This means that anything solid can stand a push or pull or twist, as long as it is not too large, without changing its shape, but a liquid cannot stand even the smallest force for long without moving.

You can make a spoon stand up in treacle for a few seconds, but it soon falls over: the weight of the spoon leaning a little to one side makes the treacle give way, for treacle is a liquid, although a very thick one. Another way of expressing the difference between liquids and solids is to say that all liquids will flow, as from a jug to a basin, but solids will not, except under enormous

pressure. That an enormous pressure will make solids flow is clear from the picture of a sheet of steel through which a shell has been fired, with tremendous energy, from a naval gun. The steel has splashed just like water into which you have dropped a drop of water or a small shot, as can be seen by comparing pictures (*a*) and (*b*) with picture (*c*); all three pictures are drawn from photographs. The blow given to the steel was so violent that, for an instant, it flowed like water. Again, bars of certain kinds of metal can be made by squeezing the metal through a hole, under very great pressure, the cross section of the bar taking the shape of the hole. For instance, if the hole is a triangle, we get a three-sided bar. Rods and bars of metal made in this way are said to be "extruded," which comes from a Latin word simply meaning "pushed out." Various kinds of brass are often treated in this way. Remember, however, that while it needs a very great push to make solids flow, liquids, even the sluggish ones like castor oil, will flow under very small forces, if given time. You can with a spoon pile up a little mound in the surface of thick oil or treacle, but it soon dis appears of itself, and the surface becomes flat again.

Different Kinds of Liquids

There are various kinds of liquids. There is the bright quicksilver, also called mercury, which is a metal, and very heavy, so heavy that iron will float on it. You can see this liquid in the bulbs of thermometers and in the tubes of certain kinds of barometers. It has a shine like a piece of lead has when freshly cut or scraped, and is opaque, which means that you cannot see through it. Another kind of liquid is the oils made from nuts and fruits of certain kinds, such as palm oil, made from the kernels of palm nuts, and olive oil, squeezed from the olive, which is a fruit like a

small green plum in appearance, and castor oil, made from the seeds of the castor oil plant. Oils of quite a different nature are found in the earth, which are called mineral oils. Lamp paraffin is such a mineral oil.

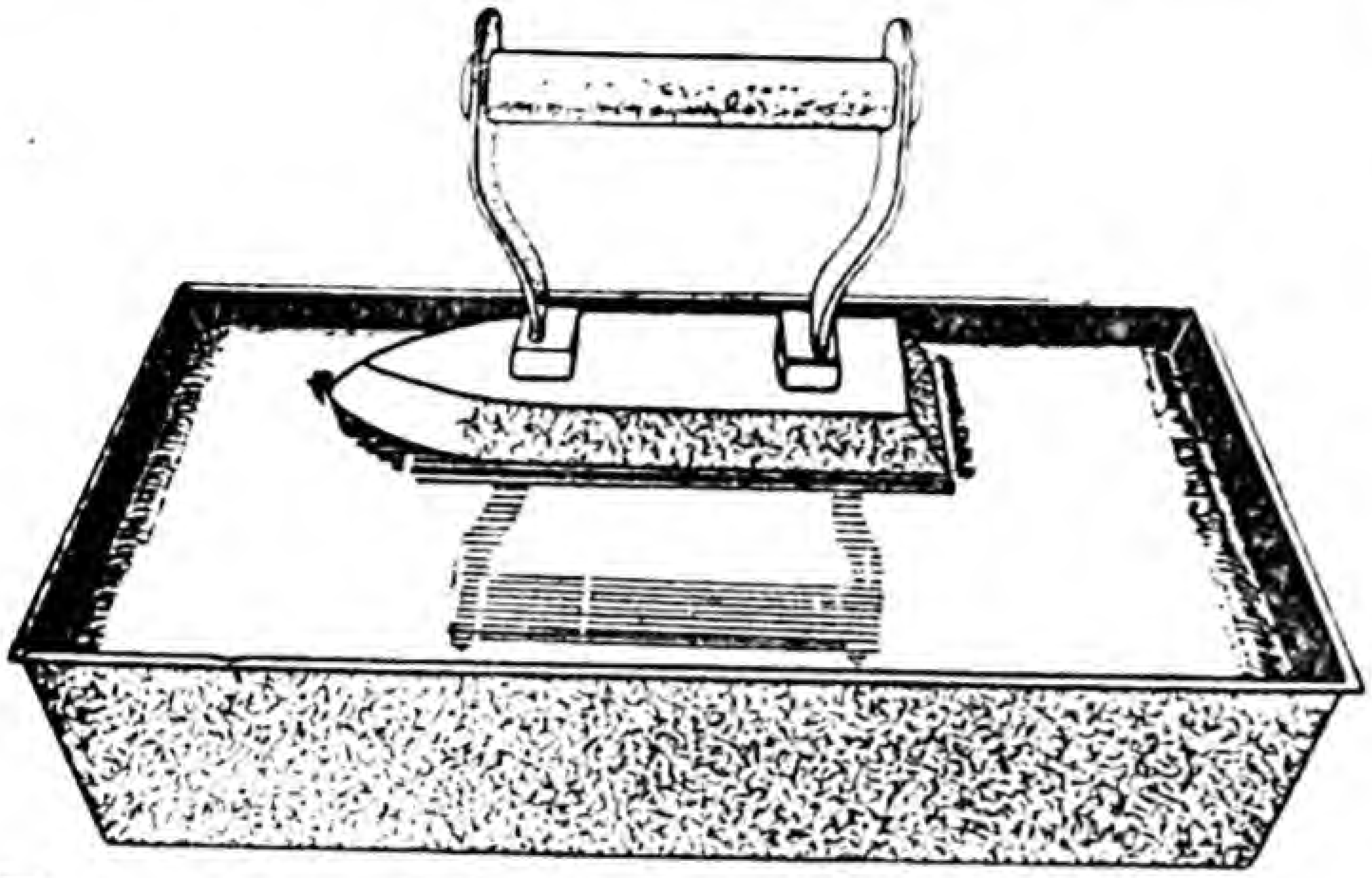


FIG. 31.—*A flat-iron floating on quicksilver.*

Alcohol is another important liquid: it is clear and colourless and flows very easily. It can be distilled from many forms of fermented vegetable matter—grain of any kind, potatoes, or molasses, for instance. There is more than one kind of alcohol. The kind that is generally called simply "alcohol" is really *ethyl alcohol:*

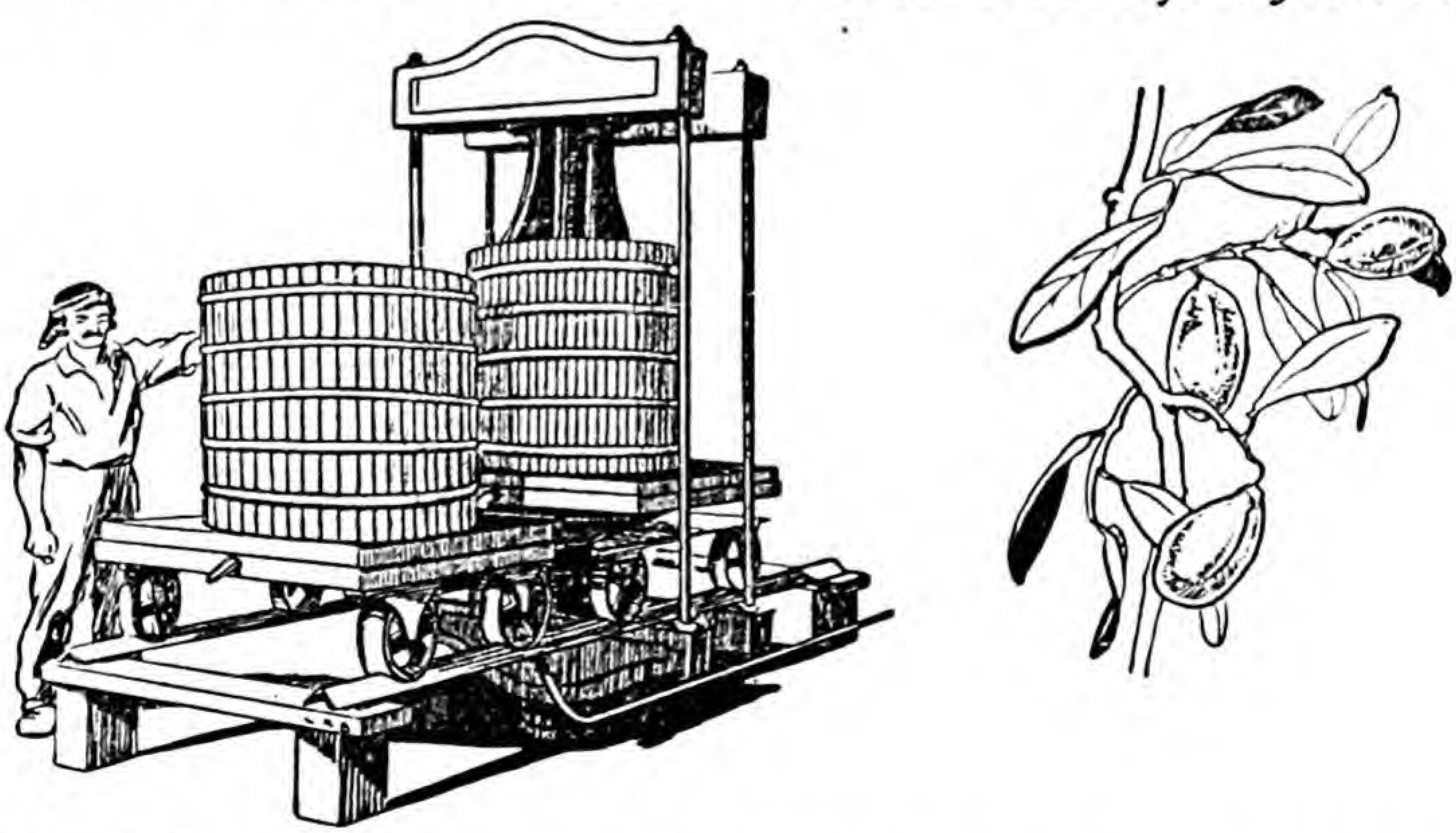


FIG. 32.—*Vegetable oils are liquids squeezed out of certain fruits or nuts. Olive oil, for instance, is squeezed from olives (shown on the right) in a press of the kind pictured here.*

it is sometimes called "spirit," but that is not a good name for it. Another kind of alcohol is *methyl alcohol.* Methyl alcohol has a very nasty taste and is mixed with ethyl alcohol to prevent people drinking it. This mixture, which is often coloured by adding a little dye, and has still other things mixed with it to make it nastier, is called "methylated spirit," and is, as everybody knows, used for burning in lamps, for dissolving varnishes and polishes, and for many other purposes. This leads us to a very important property of liquids, the power of dissolving things. Different liquids can dissolve different substances, and suitable liquids for dissolving particular things are of the greatest importance in industry. A liquid used for dissolving things is called a *solvent* by chemists. Thus, if we dissolve sugar in water, the water is behaving as a *solvent* for the sugar, while we can use methylated spirit as a *solvent* for varnish.

Water will dissolve salt or sugar or copper sulphate in large quantities. The salt, to take one substance as an example, seems to have disappeared, but it is held in the water, and if the water is boiled away just the same amount of salt is left behind as was first put into the water. So, if you have a mixture of salt and fine white sand and want to separate out the salt, all that you have to do is to throw the mixture into water. The salt will dissolve, and the clear liquid, which is water with salt dissolved in it, can be separated from the sand by pouring it through a piece of blotting paper folded into a glass funnel, a process which is called filtering. A filter is anything with very, very fine holes in it through which water or other liquid can run, but which holds back any little pieces of solid stuff which may be in the liquid. For some purposes cloth supported on a frame is used as the filter: for others a special kind of

paper, which, like blotting paper, has very tiny openings in it, is used. A third kind of filter, often used for purify-

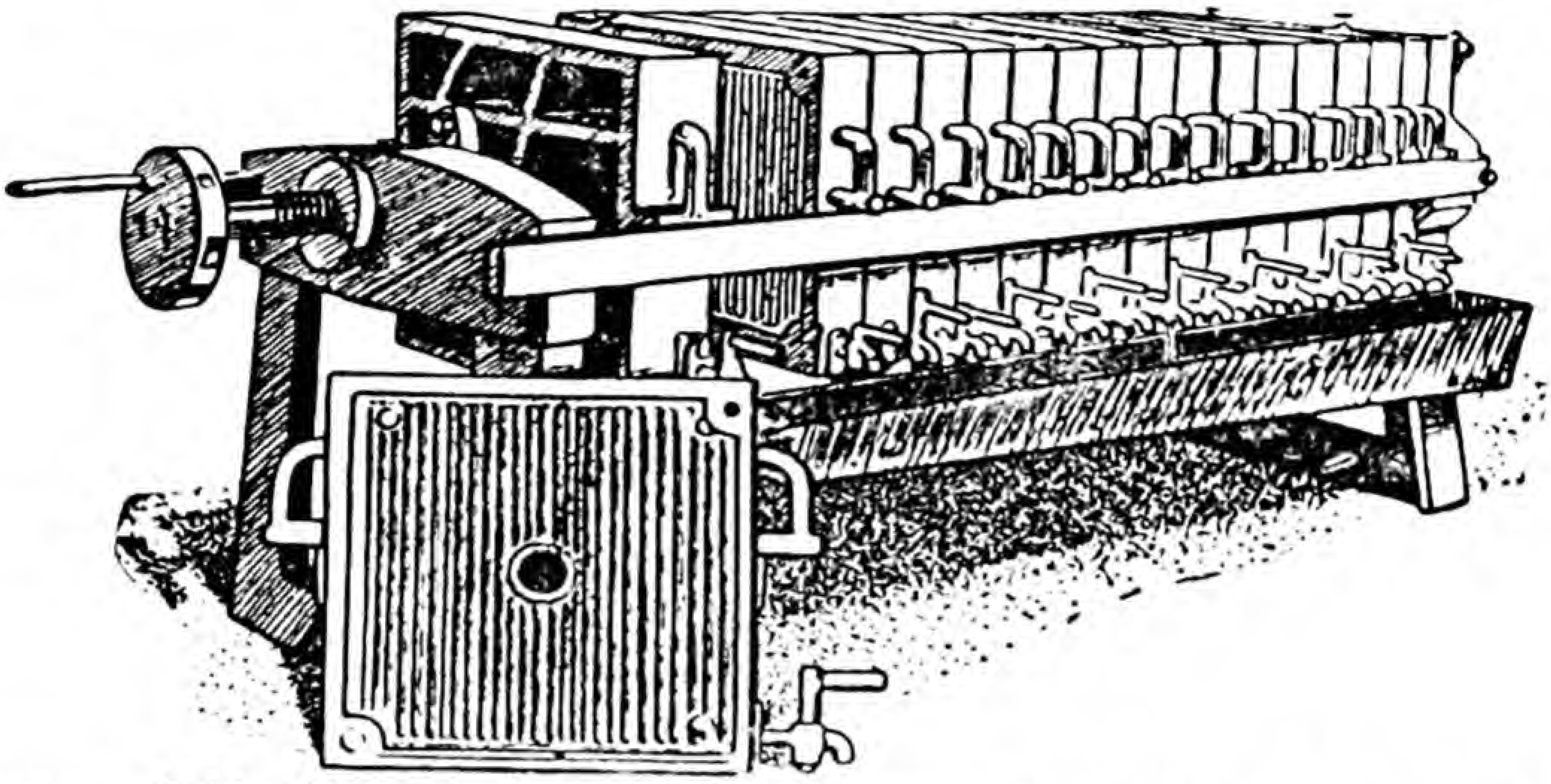


FIG. 33.—*A big filter press used for filtering in factories. The square plates, one of which is shown removed, are covered with filter cloth. The taps are to run off the liquid, which is forced through by a pump*

ing water, is made of china ware without the glaze—that is, without the shiny coating which is put on all ordinary

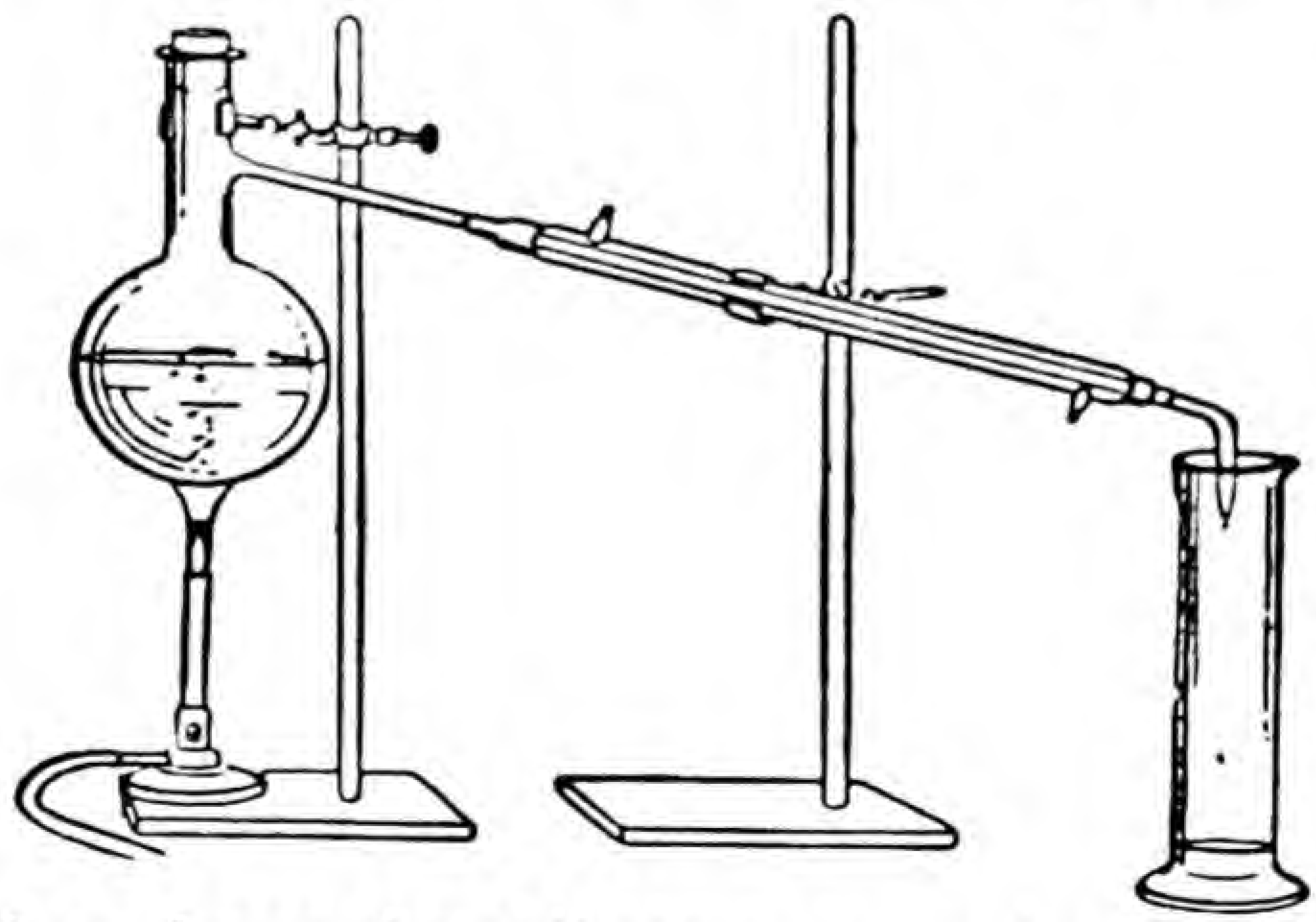


FIG. 34.—*A condenser for collecting steam that has turned to water.*

china or earthenware to cover up the tiny openings, and prevent liquid running through it. The picture shows a

big filter press used to separate the sugar juice from dirt and pieces of sugar cane. The square filter plates are covered with cloth, and the juice is forced through them at great pressure by a machine.

If the liquid which runs through the filter from the salt and sand mixture is boiled, the water flies off as steam, and the salt is left. The steam turns back to water again, and can be collected, if it is required, by making it go through a long tube kept cool by water, called a condenser. By using heat we have, then, won back again water, salt and sand, but the salt is no longer mixed with the sand. This is the kind of way in which solvents are used to separate substances.

The Behaviour of Solvents

Let us consider some of the special tricks of solvents. Mercury will dissolve many metals, such as pieces of tin or gold, but not iron, nor substances like salt, sugar, or wax. Water, which dissolves salt and sugar and soda, will not dissolve paraffin wax or sulphur or beeswax or shellac or sealing-wax. Turpentine dissolves sulphur and paint and tar, so that it is often used for taking tar off clothes or hands. When a piece of rag is dipped in the turpentine and rubbed on the tar stain the turpentine dissolves the tar, and the liquid containing the tar is mostly absorbed in the rag. In the same way petrol, which dissolves greases of all kinds, is used for taking stains out of clothes. Drop a small piece of fat or butter into petrol, and it disappears. Turpentine, however, will not dissolve sugar or salt, as water will. Methylated spirit dissolves varnishes of all kinds, and is used by French polishers to dissolve their polish, which water will not do. Glycerine will dissolve in water, but not in petrol. Benzene (or benzol, as it is

sometimes called) will dissolve fats and paraffin wax: it is used for cleaning clothes, like petrol. We should notice very carefully that the invisible vapour of petrol or benzene, or, in a less degree, of methylated spirit, mixes with the air, and that if the mixture reaches a light of any kind, it gives an explosive flash which will strike back and set the liquid alight. As draughts in the air easily carry the vapour about it is very dangerous to have an unstoppered jar of any of these liquids anywhere near a fire or light.

Solids, Liquids and Gases

We have seen, then, that we have around us gases, like air; liquids, like water; and solids, like wood. Solids have a shape of their own, and a surface. Liquids have no shape, but have a surface; they fit any vessel into which they are put, but lie smoothly in it with a flat top. Gases have no shape and no surface, and fill any sealed vessel into which they are put. If you put in twice as much gas it still fills the vessel, but the pressure inside is higher. This reminds us of another difference between liquids and gases. Gases, like air, are very easily squeezed: you can go on pumping more and more air into a motor tyre. The pressure goes up, but you can still force more in by pressing harder on the pump. Liquids are very little squeezable. If a steel cylinder is full of water it requires a great pressure to make a *very* little more water go in. Solids are, on the whole, still less squeezable, although a very high pressure all round can actually crush them into a little less space. It needs, however, a very strong machine to crush water or lead into a smaller space, and even then it can only be squeezed in a very little.

Let us think of another difference between solids, liquids, and gases. Gases flow very easily through pipes.

The air goes through the tube of a pea-shooter without any kind of sticking when you blow, and the coal gas comes through the pipes to the gas stove without any difficulty. Liquids flow too, but some flow much more easily than others. Water pours easily out of a jug, treacle does not. If we have a very long narrow pipe, water does not pass through it as easily as methylated spirit does. Some kinds of oil flow easily, others are thick. Whatever kind of liquid we think of, however, we find that it flows more easily when hot than when cold. This is why clever women dip a spoon in boiling water before helping treacle. Where the hot metal touches it, the treacle flows more easily and runs off the spoon.

Solids in the ordinary way do not flow at all, even in hundreds of years. Bronze and stone statues keep their sharp outlines, but if gold, say, flowed ever so slowly the gold figures from old Egyptian tombs would have drooped like candles in hot weather. The candles remind us that some kinds of solids will flow, at any rate if warm. It is interesting to support a stick of sealing wax at the two ends on wooden blocks and leave it for a week or two on the mantelpiece. Although it seems quite hard all the time it will be found to droop in the middle. A thin rod of pitch will behave in a similar way. A metal rod, however, will keep its shape if supported in the same way. Although, however, metals do not flow in the ordinary course of events, they will do so if sufficiently big forces are used. Coins are made by putting small discs of metal (a flat round plate of anything is called a disc) between very hard steel pieces (called dies) engraved with a pattern and letters, and squeezing the dies together by a machine. Under the great pressure the metal actually flows into the marks on the die, and takes up the shape of the die. The dies to

make pennies have, one of them, the King's head sunk in it, and the other the figure of Britannia: when the copper disc is squeezed between them it becomes a penny. Under the great pressure the metal behaves like butter, which can be stamped with patterns in a wooden mould. Another way in which we can see that metals will flow if struck hard enough is by looking at the picture of the steel armour-plate on page 44. We must not say, then, that solids cannot flow, but we can say that a true solid only flows if very strongly forced, while a liquid flows comparatively easily, especially if hot, and a gas more easily still.

Melting and Boiling

Now whether a stuff is solid or liquid depends upon how hot it is, not upon what the stuff is. Let us think of things that you know may be solid or liquid. Water is liquid, but if it becomes very cold it changes to solid ice. Lead is a solid, but in an iron ladle it can be melted over a fire, and becomes a bright liquid which can be poured like water. Tin can also be easily melted. All metals, in fact, can be melted, but some have to be made much hotter than others before they will melt. To consider a few only: tin, lead, zinc, silver, copper, iron, and the rare white metal platinum are here arranged in order, with the easiest to

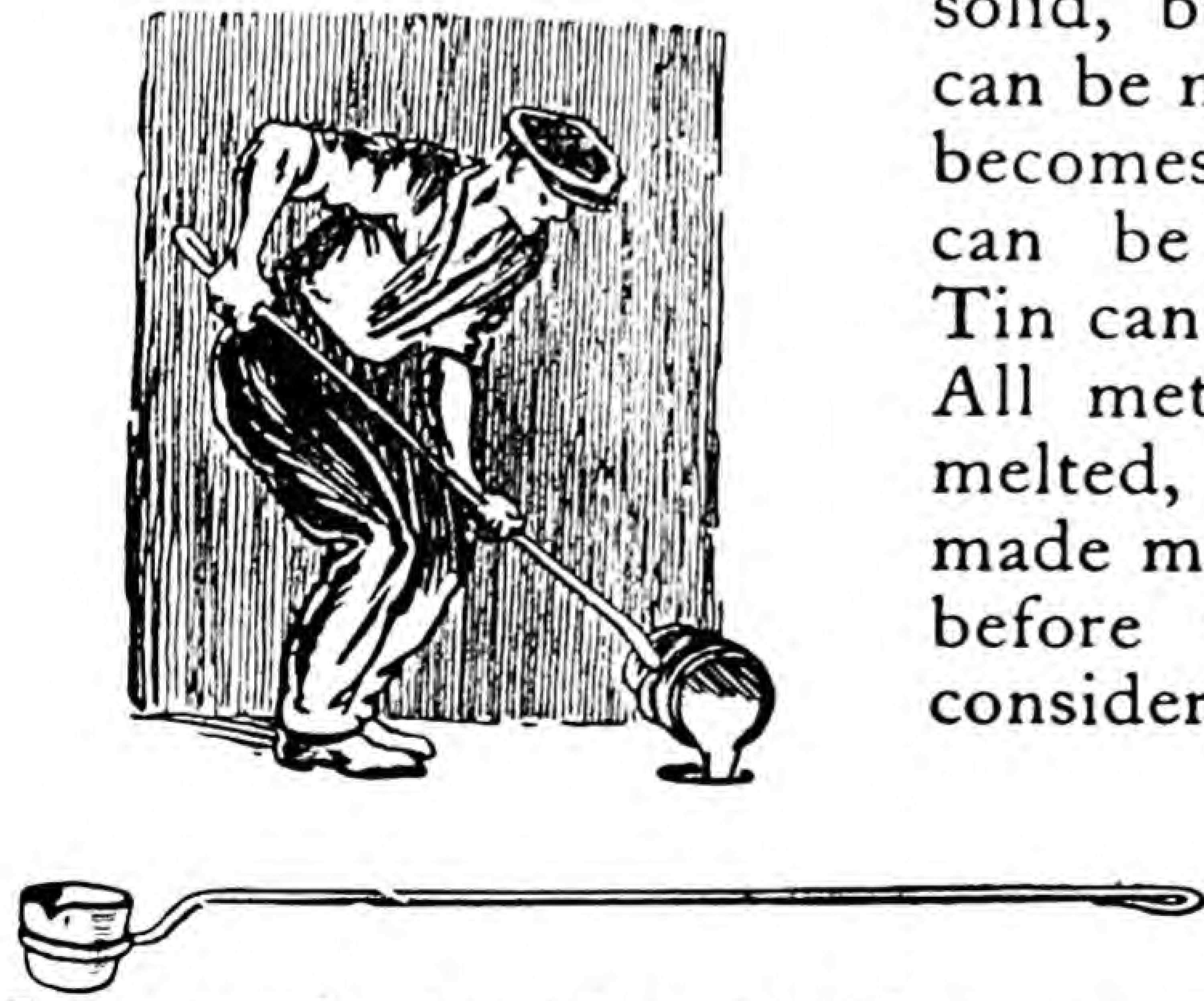


Fig. 35.—*Pouring molten metal into a mould from a hand ladle of the kind shown in the picture underneath.*

melt first and the most difficult to melt last. Melting a metal is the first step towards casting it into a particular shape. To cast a metal a wooden pattern is first made of the shape which is wanted, say a wheel. From the pattern a mould is made out of a special kind of sand, which the hot metal does not burn. The metal is then melted, and poured into the mould, where it cools and becomes solid in the right shape, just as a jelly sets and takes the shape of the mould into which it is poured while liquid.

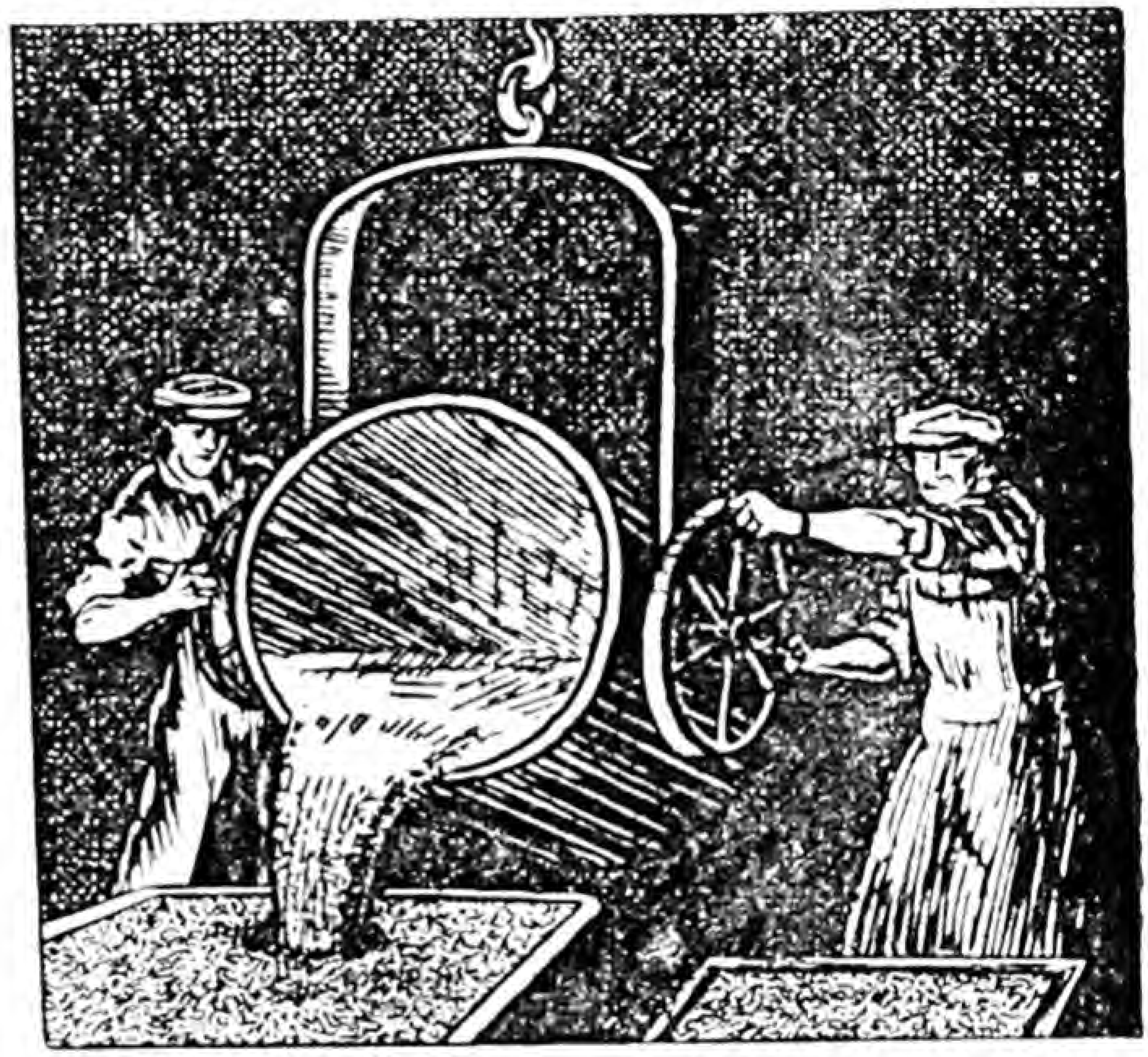


FIG. 36.—*Making a large casting. The molten metal is a liquid, and is being poured out like water.*

Ice and metals have a sharp melting point: they are either solid or liquid, and cannot be anything in between. If we look at the lead in an iron ladle we find that as it is heated a point is reached where it suddenly becomes liquid. When ice melts it becomes water, and does not go soft first. Some things, however, like butter or pitch or sealing wax or glass, get

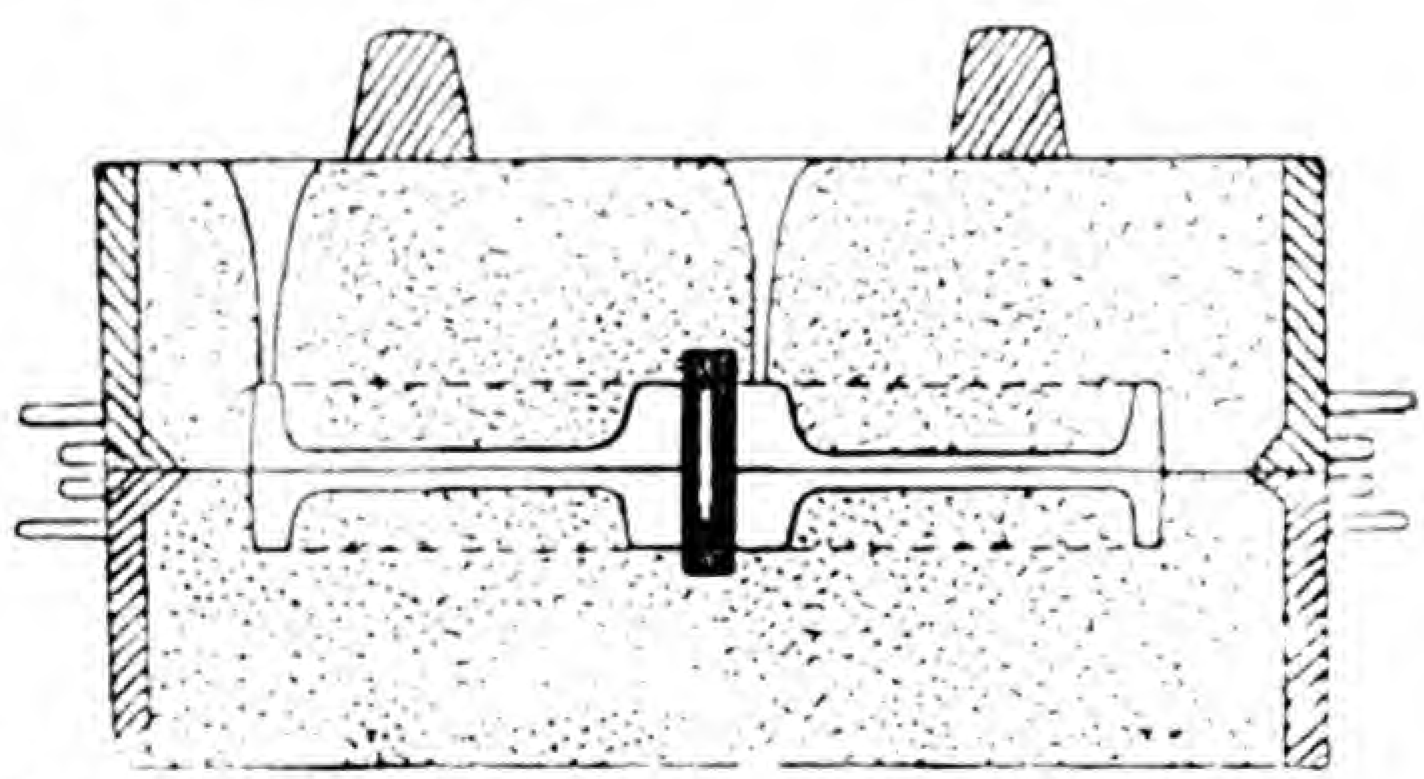


FIG. 37.—*A mould made of sand, in a case, into which the molten metal is poured. One hole is to pour in the metal, the other to let out the air and gases from the mould.*

softer and softer when they are heated, so that it is difficult to say where they leave off being solid and become liquid. These things that soften are usually mixtures made of different things. Butter, even the best butter, has water in it besides butter fat, and glass is made of many things melted together, such as sand, soda, and lime. Simple things melt suddenly, many mixed things gradually soften.

Solid things, then, can be turned into liquids by heat. Liquids, in their turn, can be turned into airy stuffs, which we have called gases, by heat. Water turns into steam, which we have seen to be a kind of invisible air. Methylated spirit also turns into a gas which very easily catches fire, so that we must be careful in heating it. By putting some methylated spirit into a glass tube closed by a cork with a glass tube leading from it, and dipping the test tube into boiling water, we can make the spirit turn into a gas which passes through the tube and can be lighted like coal gas. There is a kind of methylated spirit lamp in which the spirit is made hot and the liquid turned into methylated spirit gas which is burnt at small holes in this way.

FIG. 38. — *Burning the gas, or vapour, from hot methylated spirit.*

In a similar way, liquids that smell produce the effect on our nose because a small quantity of the liquid turns itself into vapour, which is another name for the gas form of liquids which easily pass into that state. If a bottle of scent is open we do not smell it until the air has carried some of the scent gas, or vapour, to our noses. We smell

an onion because a little of the liquid of the onion, which has the smell, turns into vapour. This vapour, which exists at the same time as the liquid in the case of petrol or scent or onion juice, is just like the water vapour which exists over water in the ordinary way, and makes, for instance, a dry cloth become damp if it is kept near water, although the water does not touch it. If, however, we heat any liquid, at last it gets so hot that it all turns into gas form, or, as we say, it boils away. If the gas gets cold it turns back to liquid, as steam turns back to water, but if it is kept hot it stays in a gassy form. We may say, then, that all liquids turn into gases if they are kept hot enough. In the same way all gases can be turned into liquids if they are made cold enough. Even air, dry air without any water in it, can be made to turn into a liquid which looks like water, but is not water: it is liquid air. This is done by a machine that both squeezes the air and makes it very cold.

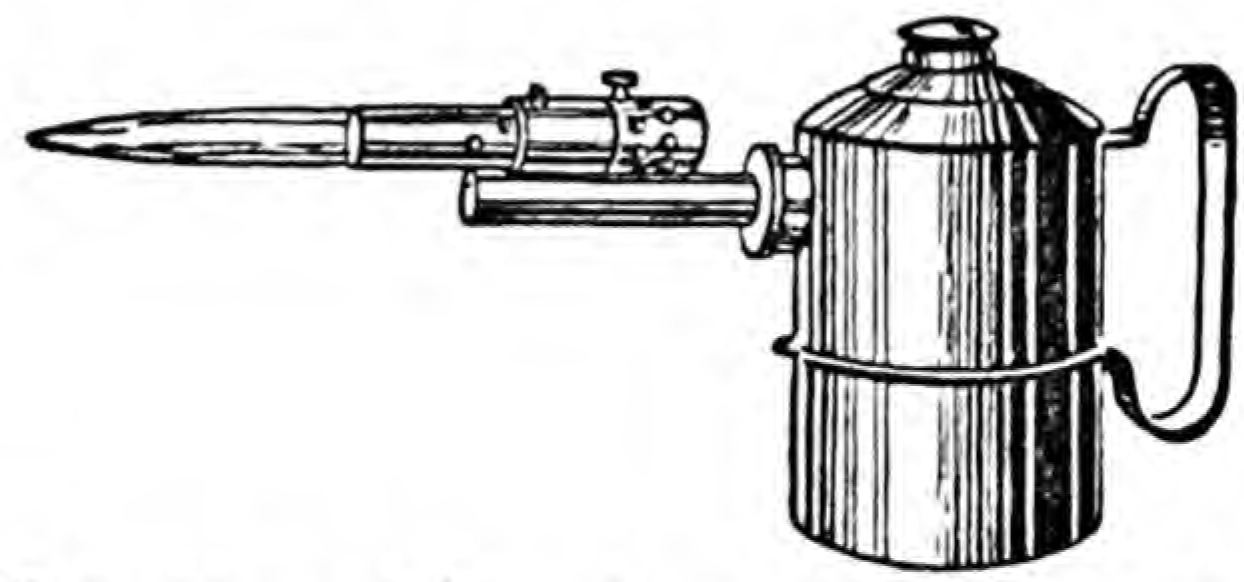


FIG. 39.—*A blow-lamp which burns the gas formed by boiling methylated spirit.*

THE SAME THING CAN BE SOLID, OR LIQUID, OR GAS

Things, then, may be solid or liquid or gas, and the same thing can generally be made to exist in all the three kinds of form by changing its temperature, just as water can exist as ice, or as liquid water, or as steam; or lead can exist as solid lead, or liquid lead, or invisible lead gas if the liquid lead be boiled. If the whole world were as hot as red-hot iron, and we were so made that we could stand this heat, we should think of water as an invisible gas, like our air, and say that clever people could actually, by

cooling it, make water liquid and even solid. Actually natives of very hot countries who have never seen ice, are very much astonished when they first make its acquaintance, and cannot understand that ordinary water has gone solid.

Generally, before we can make a solid turn into gas we have to make it liquid, but this is not always true. In a dry atmosphere snow or ice will go to invisible water vapour without passing by way of liquid water. A very familiar example of this way in which some solids can go to gas without going liquid first is provided by what chemists call naphthalene, and ordinary people call moth-balls. If you keep a moth-ball in the open, say on a shelf, and look at it from time to time, you will find that it gets smaller and smaller, but that it does not get runny, or liquid, as we call it. The solid moth-ball turns itself direct into the gas form of naphthalene, producing the smell that is supposed to keep the moth away.

If we start with a lump of solid, say ice, and melt it to a liquid, the liquid weighs just the same as the solid. This seems natural. If we then heat the liquid and turn it into a gas, which will be invisible steam in the case of water, the steam will weigh just the same as the water, but will take up very much more room. Invisible steam has weight. So has air. In fact, the air in a large room, 30 feet long by 20 feet broad by 10 feet high, will weigh about 500 lbs., and the air in an ordinary living-room will weigh about as much as a man! It is because air has weight that balloons and airships can float in it. The balloons or airships are filled with hydrogen, a gas which weighs much less than air, and wants to float up through the air as a cork wants to float up through water. Bags full of hydrogen can support the heavy parts of the airship which without them would fall through the air. We shall have more to say about this in Chapter V.

CHAPTER III

MOVEMENT AND FORCES

Engines and Horse Power

MOST of the things that you are interested in are moving, whether they be machines or men or rivers or seas or clouds. We are now going to talk about movement and the forces that make things move, or that try to make things move. To know about these is necessary not only to the engineer, but to anybody interested in any kind of science.

The first thing that we notice is that objects, not only heavy weights, but also light things like feathers and straws, do not move of themselves. If we hang up a piece of thin tissue paper on a light silk thread, or watch the little pieces of dust in a sunbeam, it may look as if the paper and the dust specks do move about by themselves. It is, however, the draughts in the air which move them. If we cover over our tissue paper with a glass bell jar we shall see that it keeps still, unless we make a draught in the air on purpose by warming one side of the jar. The warmth of the hand placed on one side of the jar will be enough. The dust specks, too, are moved about by the draughts of air, which are merely little gentle winds, just as the branches of trees are moved about by big winds or floating pieces of wood are moved by currents of water. Light things only appear to move of their own accord because they are more easily moved than heavy ones.

Let us consider how bodies (by which in science we mean anything you can handle, such as weights and bricks and balls and coins and wheels) are moved. Suppose we want to move a weight. We can push it, or pull it, or lift it with out hands, and if we do this we can feel that a force is necessary to make it move from its position of rest. We say that we have to "exert a force" on it, and even if it is a very tiny weight, say a penny, so that no "force"—in the ordinary way of speaking—is needed, we still say in science that a force is needed, but that it is a very small one. If you find it hard to think of force being required to lift a penny, imagine that a mouse had to do it, or, worse still, an ant. No matter how small the body is, some force is required to make it move.

Another way of moving the weight would be to tie a rope or a string to it, and let an engine pull—that is, exert a force on—the rope. This is what the engine at the pit-head of a mine does: it pulls the cage up by means of a rope. It is, in fact, the jobs of all engines *to make things move* by exerting a force on them. It is not sufficient to exert the force alone: if the engine pulled on the cage, and nearly moved it, but not quite, it would be exerting force, but nothing useful would be done. When an engine pulls or pushes or turns something so as to make it move, we say in science that the engine does *work*, but unless something moves we

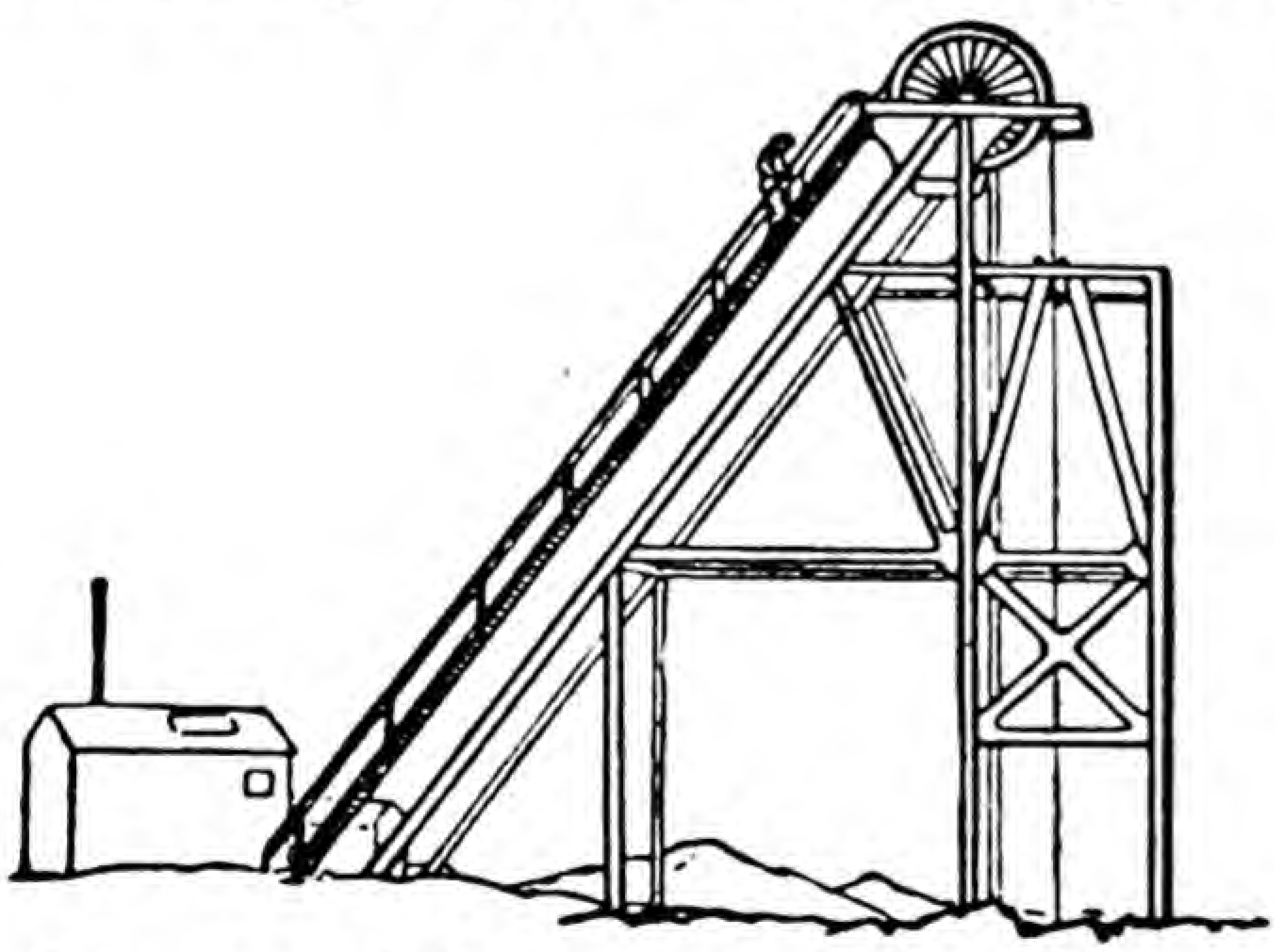


FIG. 40.—*The gear for lifting coal at the pit-head of a coal-mine.*

do not say that the engine does any work, though it may be trying. The faster the engine can do work, the more *power* it is said to have. If an engine, supposing it were set to pull a rope, can lift 330 lbs. through 100 feet in one minute it is said to be a 1 horse power engine, because that was once supposed to be what a good horse could do.

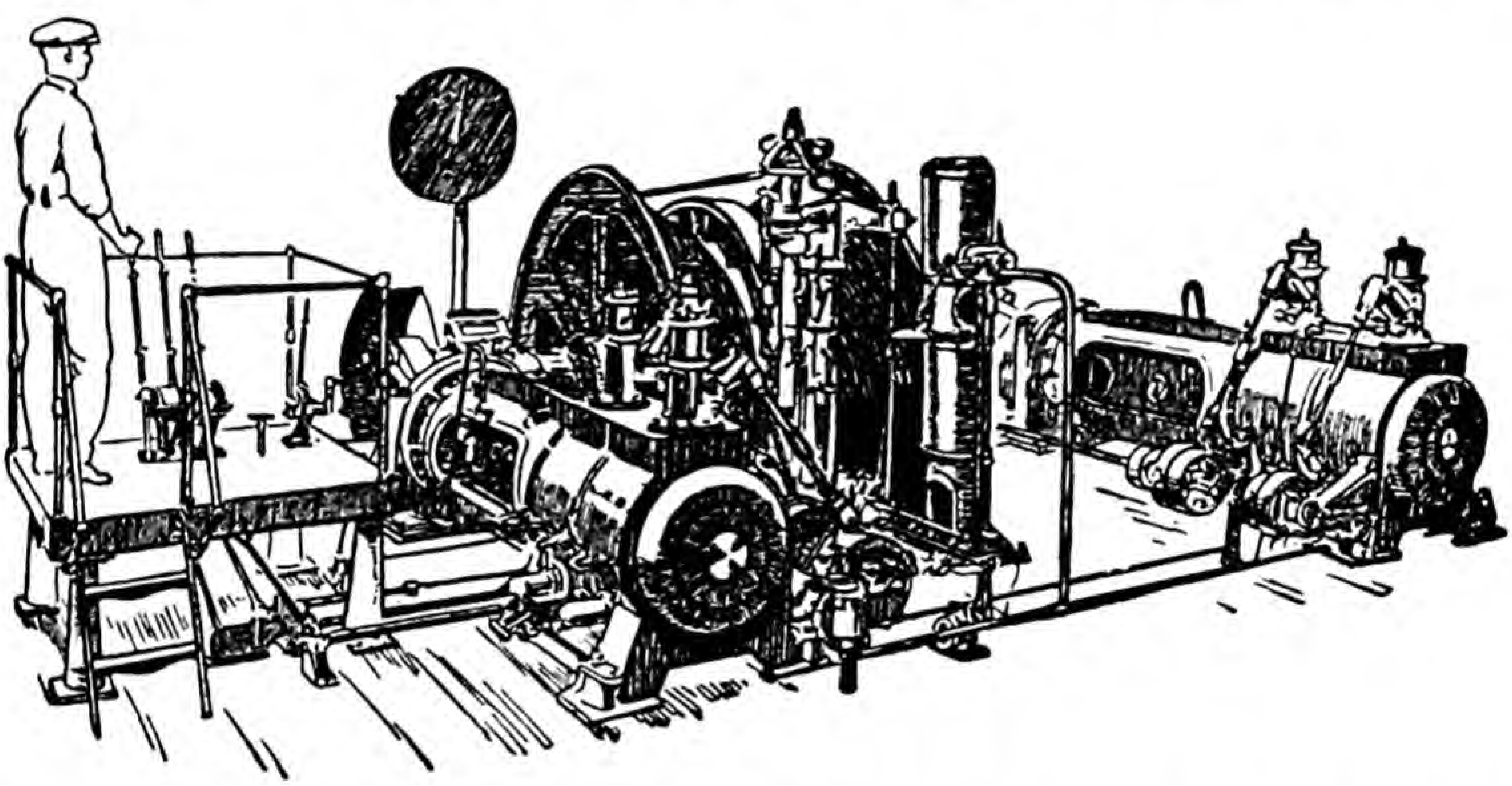


FIG. 41.—*The winding engine at the pit-head, showing the big reels on which the rope for raising and lowering is wound. The engine must be able to do work fast—that is, must be of large horse power.*

To lift this weight through 100 feet in one second would require an engine that would do work sixty times as fast—that is, an engine of 60 horse power. The power of a pit-head engine is often a few thousand horse power.[1] Motor-car engines are not actually set to work to pull up loads but the horse power tells us what loads they could pull up in a minute if they were set to do it. It is a way of telling us how fast an engine can do work.

[1] At one pit the engine can pull up a total load of 20 tons through 625 yards in 45 seconds. Let us work this out in horse power as a little

Magnetic Force

The kind of force which engines exert through ropes or driving-belts or gears or cranks—that is, the kind of force which locomotive engines and automobile engines and winding engines exert, which is the same as the kind of force as men can exert, only stronger—is not the only kind

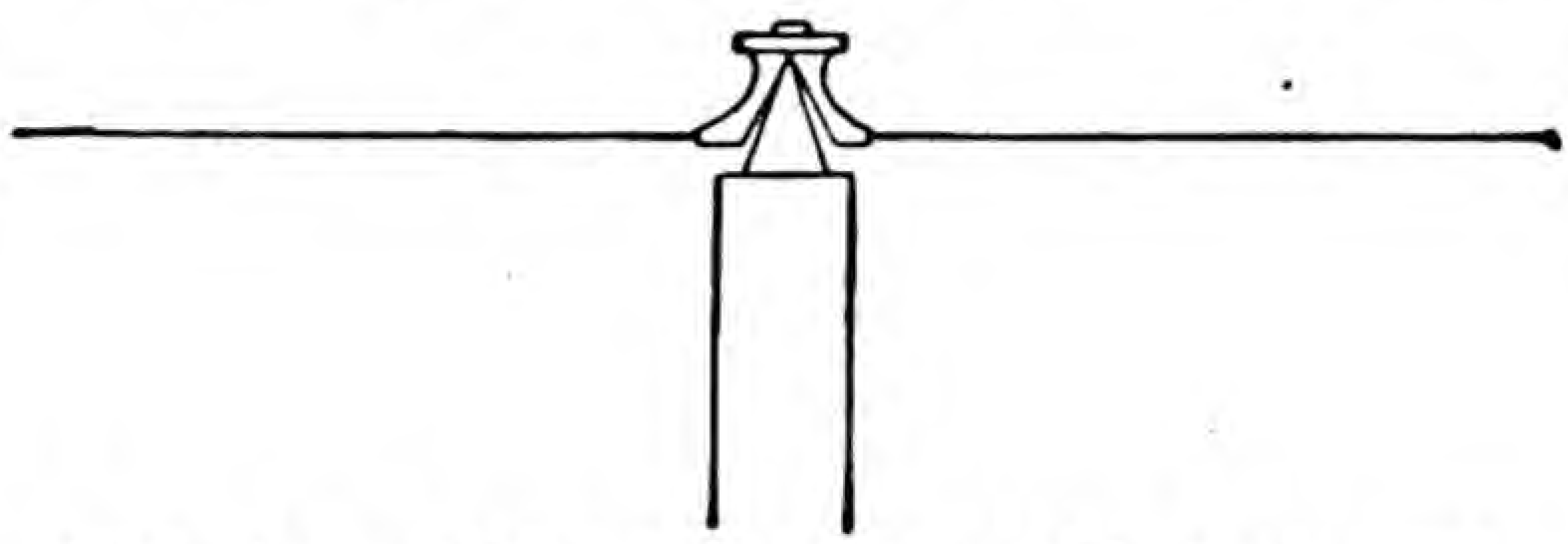


Fig. 42.—*How a compass needle is pivoted.*

of force. Let us take a magnet. A magnet is a piece of iron or steel that has been treated in a certain way, which enables it to pull or push other magnets, or pieces of iron, without touching them. Suppose we take two magnets

---

problem in arithmetic. Remembering 2,240 lbs. to the ton, 3 feet to the yard, and that 45 seconds are $\frac{3}{4}$ minute, we know that the engine does

$$2{,}240 \times 20 \times 625 \times 3 \text{ foot-pounds in } \tfrac{3}{4} \text{ minute,}$$

which is equal to $2{,}240 \times 20 \times 625 \times 3 \times \frac{4}{3}$

$$= 44{,}800 \times 625 \times 4 \text{ foot-pounds in a minute.}$$

Now 1 horse power $=$ 33,000 foot-pounds in a minute.

$$\therefore \text{ Horse power required} = \frac{44{,}800 \times 2{,}500}{33{,}000}$$

$$= \frac{112}{33} \times 1{,}000$$

$= 3{,}390$ (+ a fraction of a horse power which we need not trouble about).

That would be just sufficient horse power for the job. The engine must actually be able to do a bit more, to allow for losses which cannot be avoided.

made in the form of bars,[1] and arrange one so that it can turn easily, which is called pivoting it. One way of pivoting, which is used in compasses, is to bore a hole in the middle of the magnet and fix in it a very small thimble which then rests on a point. An easier way is to take a watch glass[2]—which can be bought at any watchmaker's—and balance a small piece of flat glass on it, on which the magnet is then in its turn balanced. It can then easily be shown that magnets exert a force on one another or upon a rod of iron or steel.

First of all, let us suppose that an iron rod is pivoted on the watch glass. It will be found that either end of the magnet will pull the iron rod if brought near to it, but not near enough to touch. The pull is shown by the rod turning so as to get as near to the magnet as possible. Now let us pivot a magnet instead of the iron rod, having first marked one end with a spot of paint or with chalk. If we hold one end of a second magnet in our hand and try the effect of the other end on the pivoted magnet, we shall find that while it will pull one end of the pivoted magnet very strongly, *it will push the other end away*. The two ends of a magnet are different, then. If we now reverse the magnet in our hand, holding the end which was free before, and pointing at the pivoted magnet the end which

FIG. 43.—*How to show magnetic forces.*

[1] Sometimes they are made bent round in the form of horseshoes.

[2] A watch can be used, but the magnet acts on the steel parts of the watch in a way that is not very good for the future going of the watch, so that it is best to use the glass alone.

we were holding first of all, then once more it will attract one end and push away the other end of the pivoted magnet, but this time the ends will be changed—the end which was before attracted is now pushed away, and the end which was before pushed away is now attracted. This once more shows that the two ends of a magnet behave differently, this time the two ends of the held magnet.

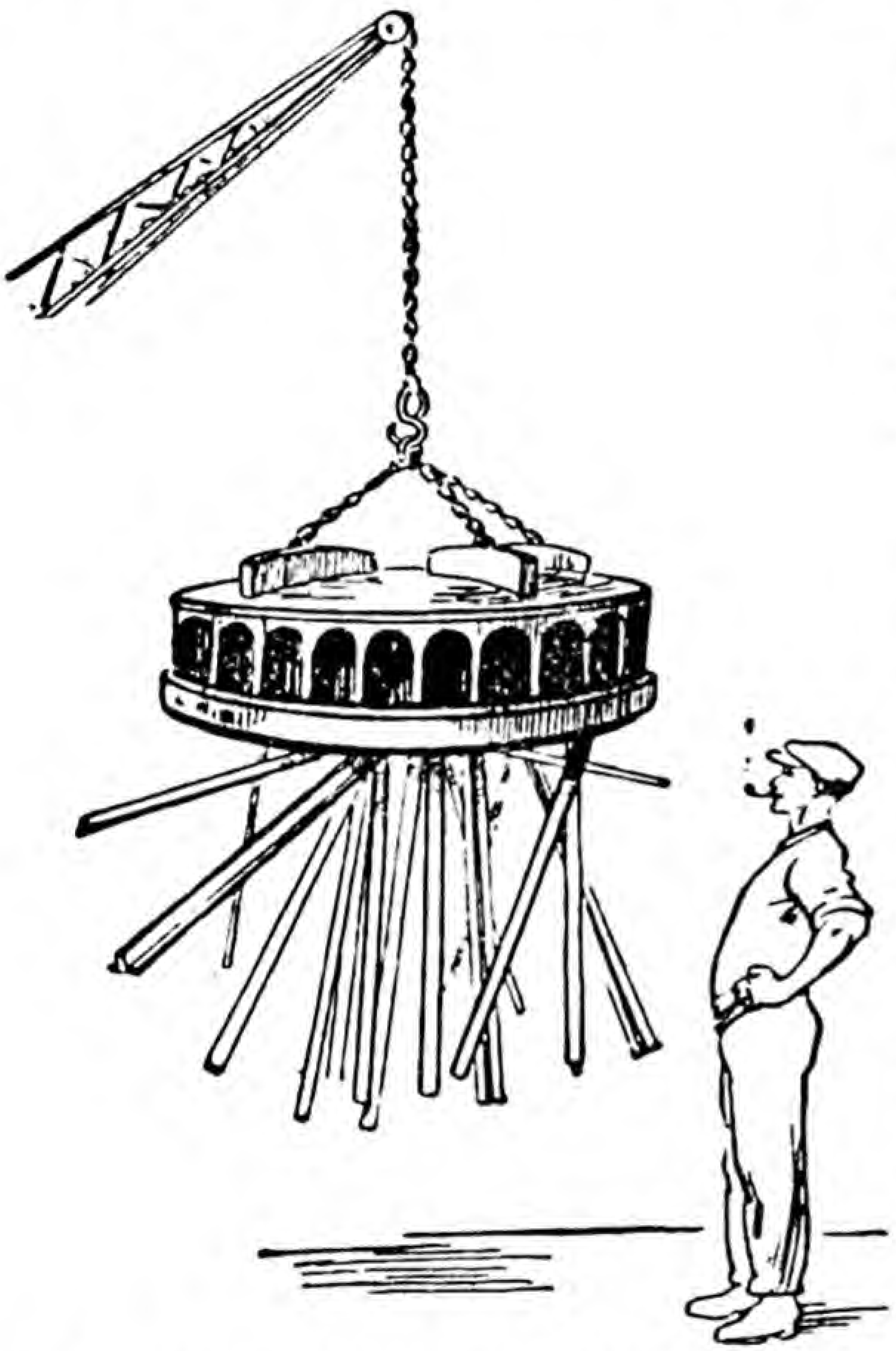


FIG. 44.—*A magnetic crane lifting rails.*

This shows us that there is a kind of force, called magnetic force, which can act where there is no touching of the bodies which push or pull. The ends of the magnet either pull one another as if joined by invisible threads (but of course there are no threads there, as we can see by putting a piece of glass between the magnets, which will not change the pull) or push one another as if by invisible sticks. This kind of force is very important, and may be made very strong. There are cranes provided with a special kind of magnet which pick up loads of iron weighing many tons. Again, the electric motors which run, for instance, electric trains, depend upon magnetic force to make them turn.

Electric Forces

We can show quite easily that there is another kind of force which can act without any touching or threads or ropes. Let us pivot a flat wooden ruler on the watch glass, as we did the bar magnet. Now let us rub a stick of good sealing wax on our coat-sleeve and hold it near one end of the pivoted stick. The ruler will turn as if drawn to the sealing wax with elastic threads. The same thing will happen whichever end of the ruler we approach—that is, an attraction will take place. We can use a stick of ebonite, or a rod of certain kinds of glass, instead of sealing wax. If we want to show a push with this kind of force we must rub the sealing wax well, and then pivot it on the watch glass, being careful not to touch the rubbed part. If we now rub a second stick of sealing wax, its rubbed end will be found to push away the rubbed end of the pivoted stick.

There are other amusing tricks which can be done with the rubbed sealing wax. It will pick up scraps of thin paper if held an inch or two above them or attract a ball made of elder pith (which is very light) if it be hung up by a long thread. This kind of force is called electric force, and it, too, is of great importance. Nobody knows quite how electric and magnetic forces act, but we know that it has nothing to do with the air, for two magnets, or two rubbed rods of sealing wax, behave in just the same way in a glass jar from which all the air has been pumped out. Electric and magnetic forces act across perfect emptiness, as if with invisible pulls and pushes.

There are other queer kinds of force. We will consider just one more sort, the force that makes crystals. A crystal is any solid thing that takes up a regular shape, with flat surfaces, of its own accord, without being cut. Thus, sugar

candy is crystals of sugar, formed on a string, and ordinary lump sugar is made up of little crystals: you will see, if you look closely, that it is a lot of little natural cubes stuck together. Soda is a crystalline substance, but indiarubber and earthenware and leather do not form crystals of this kind. If we powder up a crystal very fine, and dissolve it in some liquid, there is a strange kind of force which builds up the crystal again if we let the liquid dry up or help it to dry up by warming. As it dries away all the invisible dissolved stuff is arranged into a pattern by invisible forces between the little bits. For instance, let us powder up some alum, and dissolve it in hot water. If we leave the liquid for a day or so, we shall find that beautiful crystals of alum have been formed by the secret forces, just as if each tiny bit of alum was joined to every other bit by an invisible elastic thread which slackened when we dissolved it in water, but shrank up and pulled the whole thing into order again as the water cooled and dried up. Nobody quite understands how these forces work, but by dissolving and drying up we can control the invisible forces just as we do the pushes and pulls of engines, and in chemical factories they have to study these forces of crystallisation just as the engineer studies steam or electricity.

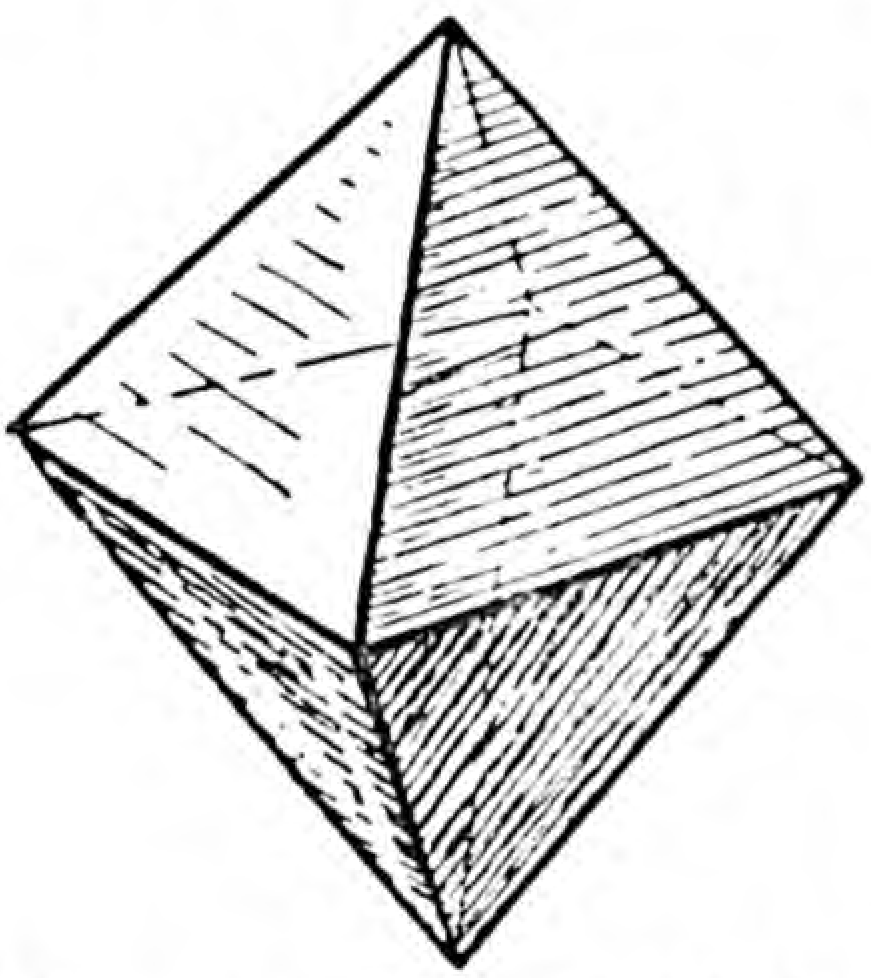


FIG. 45.—*Crystal of alum.*

THE FORCE OF GRAVITY

Now that we have seen that there are many kinds of forces that can pull things about without strings or anything else fastened to or touching them, let us come back

and consider the movement of ordinary things, such as stones and sticks and apples. We have said that things do not move of themselves. But if the stalk of an apple becomes weak, it does move without wind or without anyone pulling it: *it falls* of itself. If we hold a stone and just let go, without any push, it too moves: *it falls. Everything, in fact, falls unless it has some support*, for instance, a table under it, or a string tied to something to keep it up. We must therefore suppose that there is some force pulling everything downwards. We can say that everything behaves as if the earth were pulling it straight down, and that, unless we do something against this pull, things move downwards. We need not be surprised that the things move without anything that we can see pulling them, for we have seen that electric and magnetic forces move things without anything we can see to pull by. There is, then, this special kind of force that pulls things to the earth, but it is not magnetism or electricity. It has a special name, and is called *the force of gravitation* or *the force of gravity*, whichever you like. If you jump up, you move against this force, and you must think that the reason you come down again is that the force of gravitation is pulling you down, just as if you were fastened to the earth by elastic. If a girl were fastened to a tree by long and strong indiarubber cords, she would be able to jump away from the tree, but the elastic force of the cords would pull her back. The force of gravitation is just as real, and if it is invisible, so is the magnetic force that pulls tons of iron to the magnet in the crane in the picture in Fig. 44.

As a matter of fact, any piece of stuff attracts any other piece by the force of gravity. Two balls hung up really pull on one another very slightly, but the pull is very much too small to be measured in the ordinary way.

The earth, however, is such a big ball that its pull is very strong. Actually if we have a big enough lump we can measure its pull on an ordinary ball. For instance, if we go near the side of a steep mountain, the mountain is a sufficiently large lump for its pull to be just noticeable, and careful measuring has shown that a plumb line—that is, a weight on a string—does not hang perfectly straight down there, but is pulled in a little to the mountain: not very much, but enough to be measured.

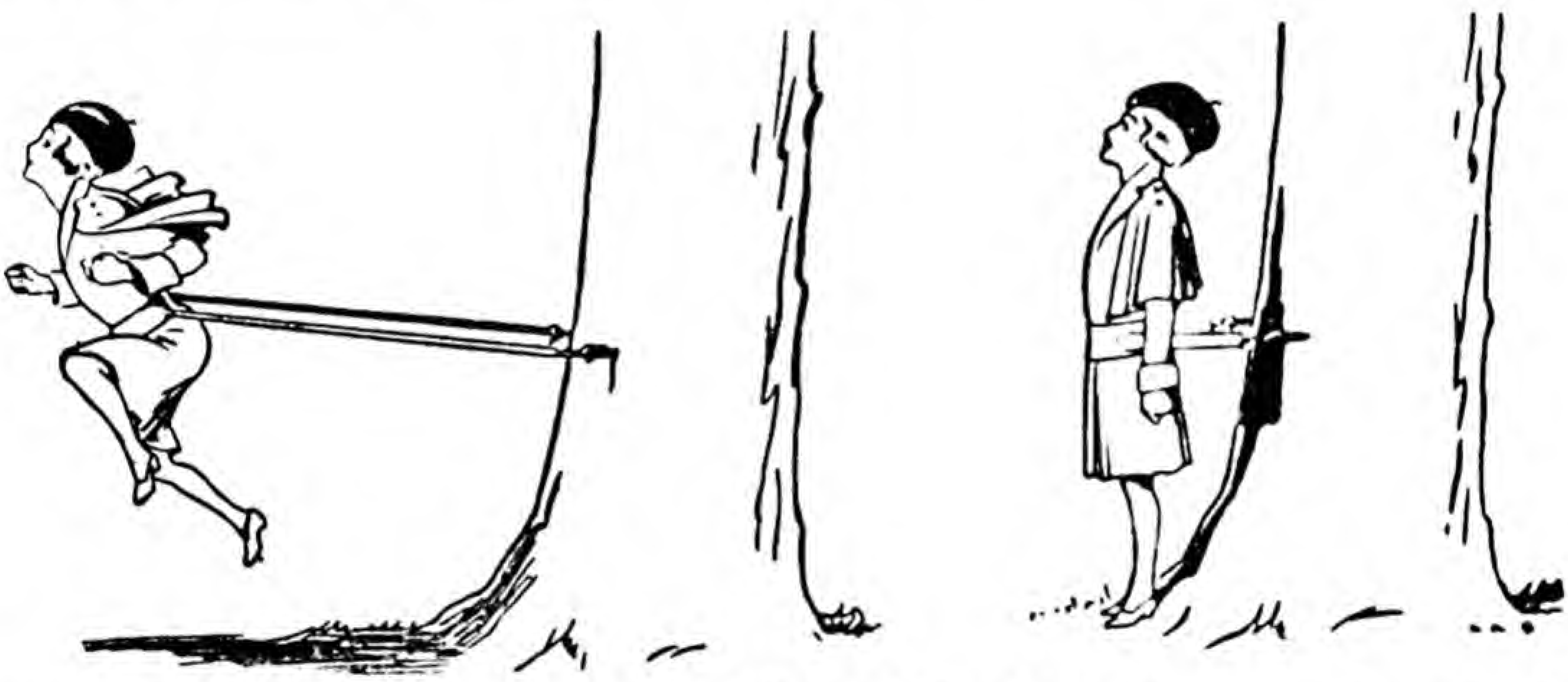


FIG. 46.—*Visible elastic cords pull the girl back to the tree when she jumps away. Invisible forces pull you down to the earth again if you jump upwards.*

The pull of the ball of the earth draws everything towards its centre, only, of course, when things have fallen to the ground they cannot drop lower, although the pull still acts on them and makes them press on the earth. They get as low as they can: if you let go a stone above a mine shaft the earth pulls it down towards the centre, and it falls until it is stopped by the bottom of the mine. In the old days people could not understand how the world could possibly be round. They said that the people on the other side would be upside down, and would then fall off the

world: they supposed that of the English and the Australians, for instance, one lot would be right way up, and the others the reverse way. Now let us think what we mean by "right way up." We mean with our feet on the earth and our head in the air, and that if we jump up we are pulled down again until our feet are on the earth. The earth is so big that any piece of country in which we happen to be does not show any general curve: it may have hills and valleys, but we cannot see the roundness of the earth. Wherever anybody is, the pull of gravitation drags things downwards towards the centre of the earth. The person's feet will be on the ground, and he will stand upright if he keeps himself straight, or, if his knees give way, he will fall to the earth. It clearly does not matter if he is in England or Australia, down he will come, pulled in towards the centre by the earth, and only stopped from going right to the centre by the ground itself. Everybody is right way up, and nobody can fall off the earth.

It has been already said that the pull of gravity is strong because the earth is so big. It is the pull of the earth that keeps the moon where it is. The moon is moving round and round this earth, and if there was no pull on it, it would fly away, just as a ball swung round and round on a string will fly away if the string breaks. But if the string does not break, it keeps a steady pull on the ball, which then stays in its path round and round the hand. The pull of gravity is like an invisible rope holding the moon. In the same way the gravity pull of the enormous sun keeps the earth (which goes fast round and round the sun, and would fly off if it were not dragged in) in its path.

It is strange to think that, as the moon has much less stuff in it than the earth (it is much smaller, and made of rather lighter material), it holds things which are on its

surface much more weakly than the earth holds things on its surface. Its pull is comparatively feeble. If you were on the moon—and could breathe there—you would be astonished to find that you could jump about six times as high as you can on the earth: a good jumper would be able to clear a two-story house with ease. On the other hand, on a big planet like Jupiter, you would be pulled down so strongly that your legs would soon get tired of fighting against the pull and you would have to lie down. It would be as tiring to walk as if you had on your back someone heavier than yourself, and even the best jumper would be quite unable to jump on to a table.

Weighing Things

Let us consider how we measure the pull of gravity on any piece of stuff, say a piece of cheese. Clearly we can hang the cheese up and measure the force which is needed to keep it there. This we can do by hanging it on to a spring and seeing how much the spring stretches. A spring balance, which is made up of a spring in a long case, with a little pointer to show where the end of the spring has stretched to, is really a measurer of gravity pull. But there is another way in which we can make the measurement. The pull on a certain piece of metal, say of brass and iron, is always the same at the same place. We can keep different-sized pieces of metal, and balance the gravity pull on our cheese against the pull on chosen pieces of metal.

This, as you know, is just a long-way-round description of weighing a thing. The pieces of metal you call weights, and you put weights in one pan of the scales and the piece of cheese in the other pan, and alter the weights until the scales balance. When they do this, if the scales are properly made, with both arms equal, it means that the forces

on the two sides are equal. In weighing anything, you are really balancing forces. There is a tug-of-war between the gravity force on the one side of the scale and that on the other, and you arrange so that neither side gets the better of it. At least that is what honest tradesmen do. Some, who are not quite so honest, have ways of favouring one side—I need not say which.

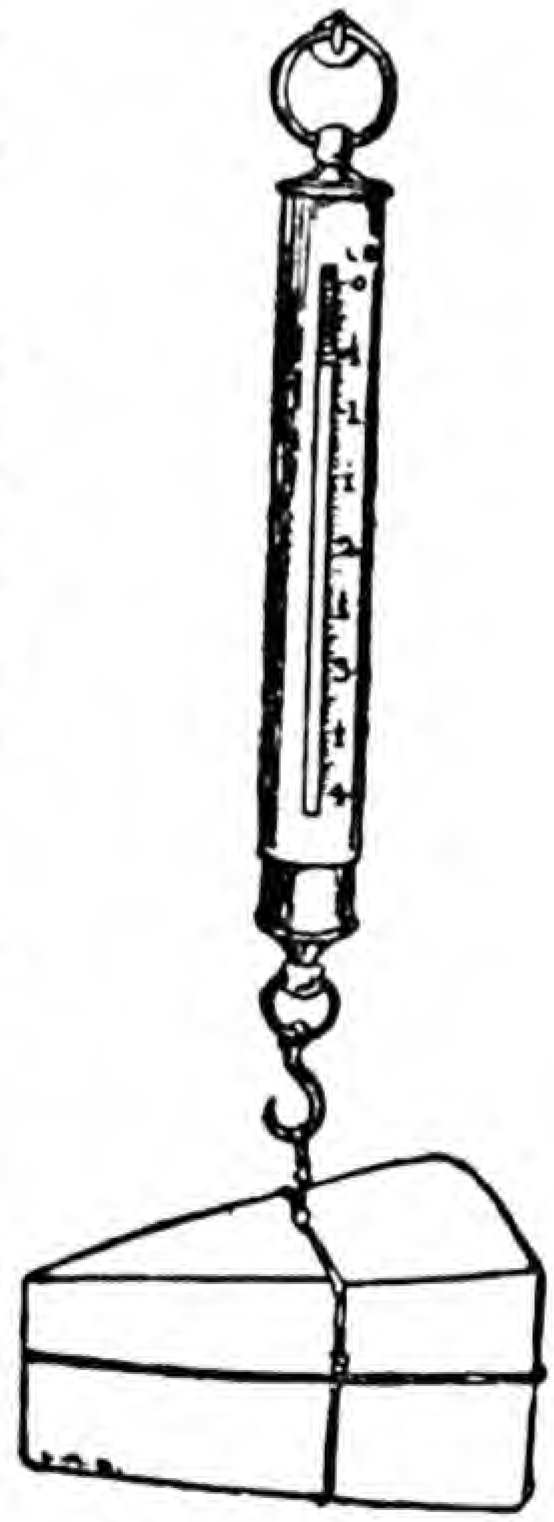


FIG. 47.—*A spring balance.*

The scales are generally more convenient than the spring balance, which often sticks a little and so does not weigh very well, but a really carefully made and well-designed spring balance has one advantage over scales. The gravity pull of the earth depends upon our distance from the centre of the earth: the farther off we go from it the weaker the pull becomes, just as the farther off we go from a lamp the weaker becomes the light reaching our eyes. Now the earth is *nearly* a sphere, so that all points on the surface are *nearly* the same distance from the centre. However, the earth is actually flattened a little at the poles so that at the Equator a man is a little farther from the centre than he is in England or Australia or South Africa. Besides that, we know that at the top of a mountain a man must be a little farther from the centre than on a plain. We can therefore understand that the gravity pull on a piece of iron, say, is not quite the same in different parts of the world. A pair of scales will not show this, because the gravity pull on the weights changes too. If we were to weigh the iron near the North Pole (or the South Pole) and then go to the Equator, the pull would be less by about

1 part in 200: that is, if the good spring balance showed a pull of $12\frac{1}{2}$ pounds, that is 200 ounces, at the pole it would only show 12 pounds 7 ounces, that is 199 ounces, at the Equator. On the scales, however, we should see no change, for the pull on the weights would also be less by 1 part in 200. There are today such good ways of measur-

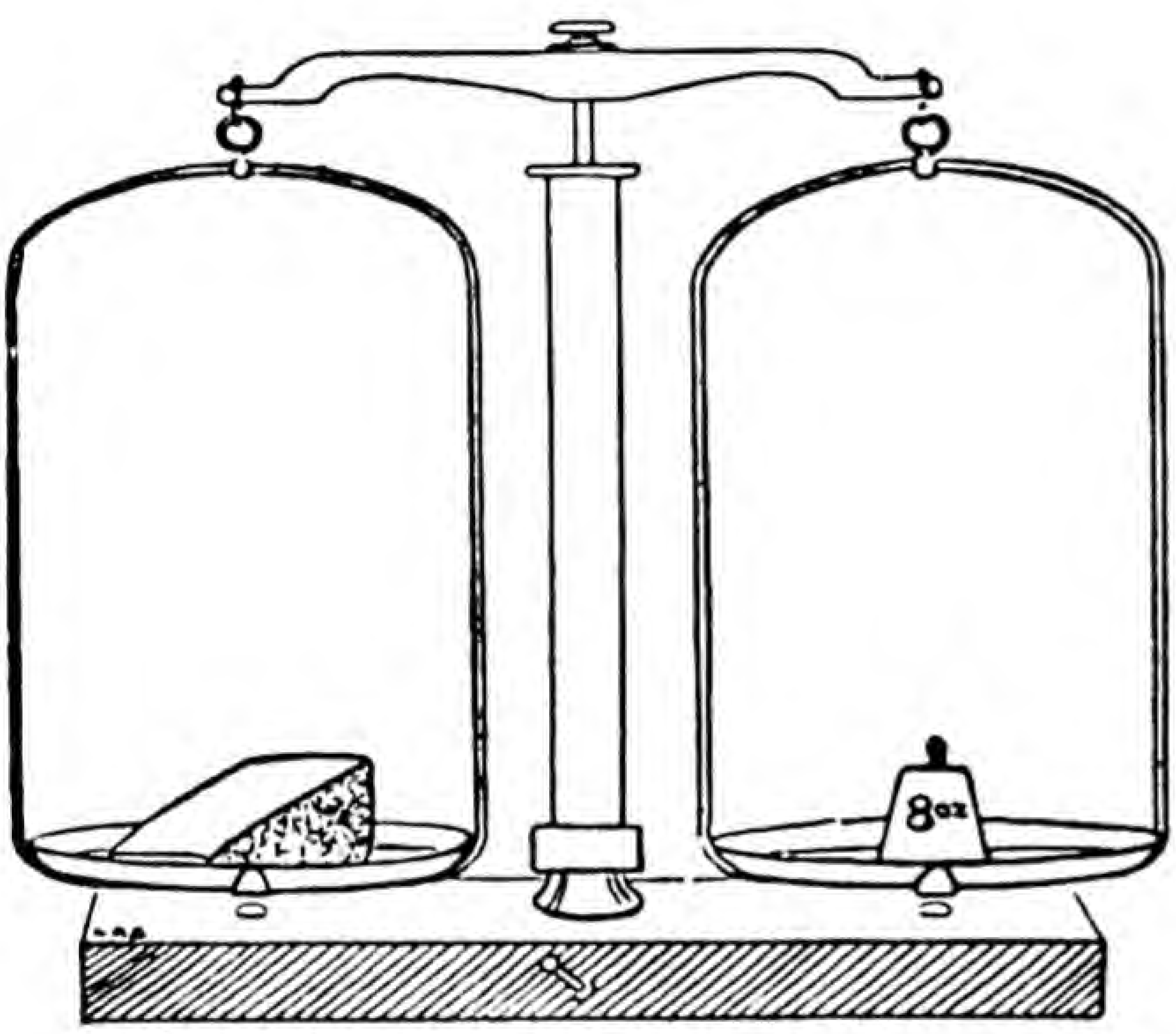


FIG. 48.—*A pair of scales in which the gravity pull on the weight is balanced against the gravity pull on the cheese.*

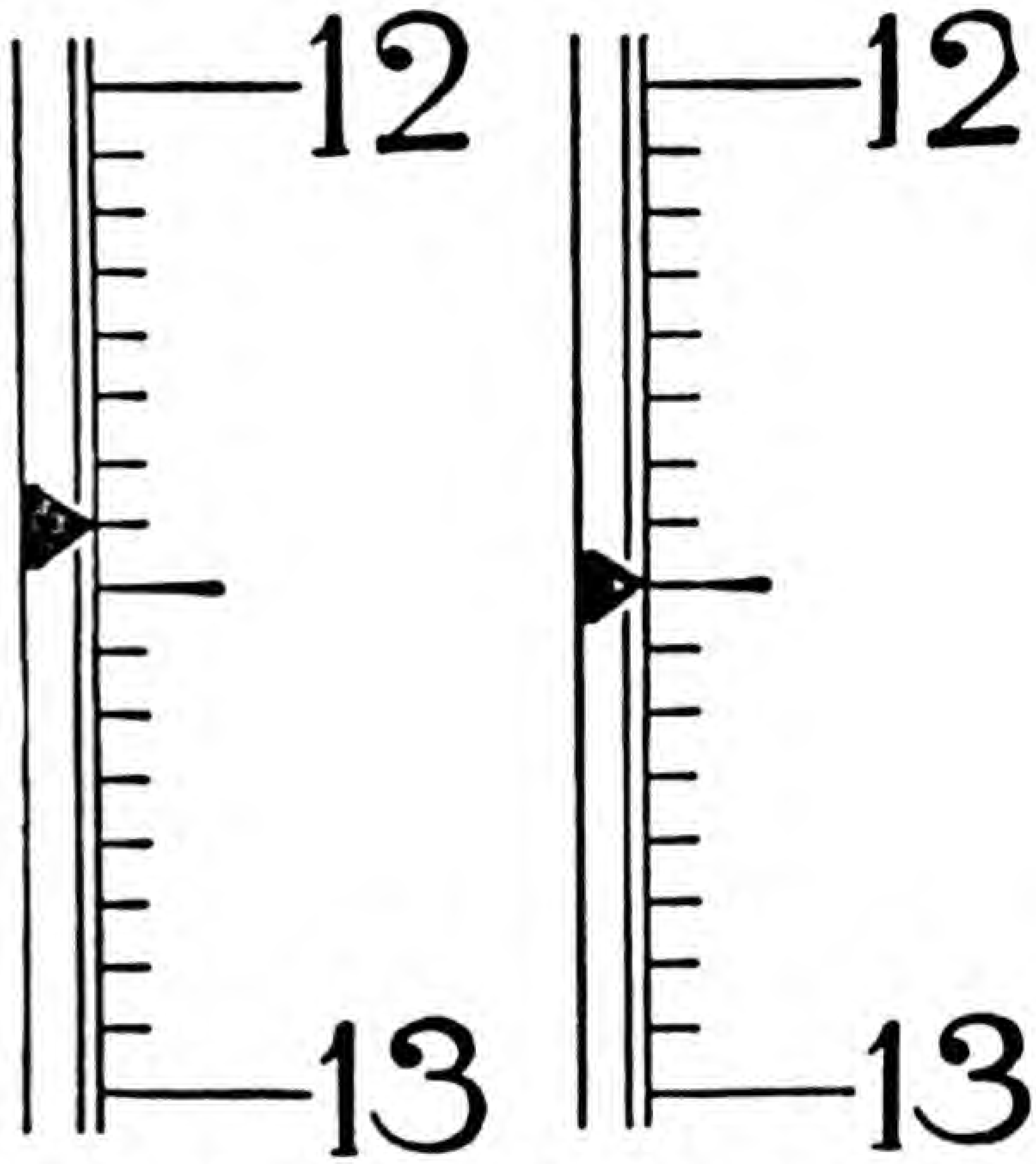


FIG. 49.—*A good spring balance which registered 12 lbs. 7 ozs. at the Equator, as on the left, would show 12 lbs. 8 ozs. at the Pole with the same load.*

ing the pull of gravity that people can find out where large lakes of oil are hidden under the earth's surface by measuring the pull: as the oil is much lighter than earth or rock the pull is a very little less over the oil lake than it is away to one side of it. The instrument which they use to measure the earth's pull is really a very, very delicate kind of spring balance.

THE WAY THINGS FALL

Let us now consider how things fall. They fall because the earth pulls them. The heavier a body the bigger the force with which the earth pulls it, but also the more of it there is for the force to move. The result is that all bodies, light or heavy, really fall with the same speed, starting from nothing and getting faster and faster. Light or heavy, all bodies take the same time to fall to the ground from a height, say from a bedroom window. You can see this if you drop a penny and a pound weight. If, however, you drop a feather or a piece of thin paper it goes down very slowly compared to the penny or the weight, and you might think, therefore, that what has just been said is untrue. The reason, however, that the paper falls so slowly is that the air stops it. The force with which the air acts against the motion of anything moving through it depends only on the size and shape of the thing: it is the same for a penny and a piece of tissue paper the size of a penny, and is very small in both cases. Against the pull of the earth on the heavy penny the air resistance can do very little, but against the feeble pull of the earth on the paper it can make itself felt. It is just as if a boy and a dog

FIG. 50.—*A feather falls much more slowly than a weight or a penny if the air is allowed to interfere.*

and a mouse could run equally fast and you then tied a cotton reel to each. The boy and the dog would still run equally fast, just as the pound and the penny fall equally fast, for they would not notice the little extra weight, but the poor mouse would be heavily handicapped, just as the piece of paper is.

If, then, we can think of a way of preventing the air getting in the way of the paper, the paper should fall as fast as the penny. It is quite easy to show this. Cut a piece of thin paper (cigarette paper will do nicely) a little smaller than a penny, and hold the penny horizontally (that means as it would lie on a table, not on edge) with the paper on it. If the penny is let fall from this position it will clearly keep the air from getting under the paper and stopping it. Drop the penny and you will find that the paper falls with it, just as if it were stuck to it—in fact you may have to blow it off, to prove to people looking on that it is not stuck to it. Another way of showing the same thing is to put a feather in a clear glass bottle, with a wide neck, and let the bottle fall on to a cushion, so that it does not break. The feather will fall with the bottle and keep in the bottom of the bottle all the time. If the bottle fell faster than the feather the bottle would leave the feather

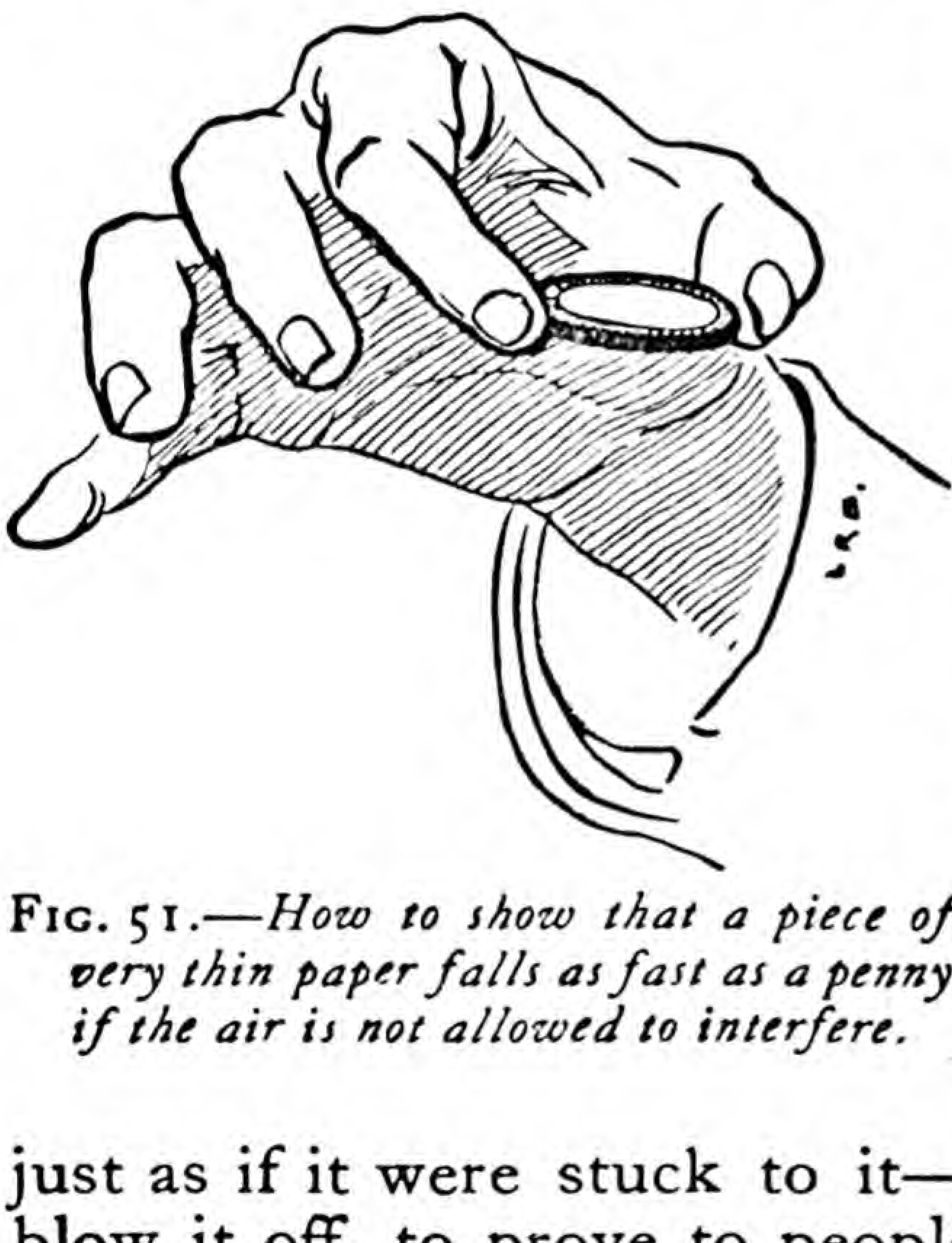


FIG. 51.—*How to show that a piece of very thin paper falls as fast as a penny if the air is not allowed to interfere.*

behind and the feather would float out through the wide neck. The bottle keeps the air from stopping the falling feather. A more difficult way of showing the same thing is to have a long wide glass tube and to pump all the air out of it. If there is in the tube a little clip, which can be opened from outside, to hold the feather and a coin, it will be seen that, if they are both let drop at the same instant, they reach the bottom at the same time. Apart from the air, then, all things, light or heavy, fall at the same rate.

The Centre of Gravity

Let us consider this pull of gravity a little more, for clearly, as all things feel it, it is very important. We have seen that, although there is nothing fastened to the things which it pulls, they behave just as if dragged down by a cord. But when we drag a body with a cord what happens depends upon where the cord is fastened. For instance, suppose that a man is dragging in a boat to a landing stage. If the rope is fastened to the bow, she will come in bow first, but if it is attached to the stern, she will turn round and come in stern first, although the pull is in the same direction in both cases. Or consider a man planing a piece of wood on a carpenter's bench, with the wood against a stop. If his push is opposite the stop, the wood will remain in position, but if his push is right to one side of the stop, the wood will turn round and slip past the stop. What happens, then, depends not only upon the direction of the forces of push or pull, but upon the point at which they are applied.

Studying this difficulty, we find that in every body there is one point, called *the centre of gravity*, at which the pull of gravity seems to act. Gravity pulls, of course, on

every piece of the body, but all these little pulls act together as if coming at this one point, as if there were a cord pulling downwards fastened to this one point. To make this clear, we can take a flat piece of wood, with holes bored at different points near the edge all round, and hang it on a nail by one of these holes. Then, if the effect of the pull of gravity is a downward force at one point, clearly that point will get as low as it can, and will be somewhere in the downward line under the point by which the board hangs. With the help of a plumb line—that is, a small weight hung on a string—we can mark this line with pencil on the board, but clearly we cannot so far say at which point of the line the pull comes, for the board would balance at the same position for a downward pull at any point of the line. We can, however, now take the board and hang it by one of the other holes.

FIG. 52.—*Finding the centre of gravity of a flat piece of wood.*

Again we can find and draw on the board a line, in which the centre of gravity, at which the pull acts, must be. We now have two different lines on the board, and the centre of gravity must lie in each. How can that be? Well, if the centre of gravity is at the point where the lines cross, then it is in both lines, but if it is anywhere else, it cannot be so. This crossing point fixes the centre of gravity.

Suppose we now hang the board up by still another hole: then, if we are right, this point will still try to get as low as it can, and will place itself in the direct downward

line below the point of hanging. Try it, and we shall find that this is so: in fact, no matter by which point we hang the board, it will *always* come to rest with the centre of gravity as low as possible—that is, dead below the nail from which it hangs. If we bore a small hole at the centre of gravity, and fit it over a headless nail driven into the wall, we shall find that the board will stay in any position we like, as the centre is at the nail and cannot get below it.

It is more difficult to find the centre of gravity of a thick body, such as a brick or a china figure, because the centre lies right in the middle of the solid, but it is there just the same. The centre of gravity of a solid cube or of a sphere or of a round rod or an oblong block is at the central point, if the thing is made of the same stuff all the way through—that is, for example, if it is all wood or all iron.

The Conditions for a Body to Stand Up

Now let us mark on one side of a tall oblong block of wood a cross opposite the centre of gravity, as in the picture, and stand the block on a small plank. Let us tilt the plank and find just the position at which the wooden block falls over. Then let us prop the board in that position, hold the block on it, and pin to the centre of gravity mark on the side a piece of cotton carrying a small weight. We shall find that the piece of cotton passes *just* outside the edge of the bottom of the block, as shown: that is, the downward line through the centre of gravity passes just outside the base of the block, the base meaning the flat surface on which anything stands.

This is what we ought to have expected. When the downward pull is inside the base it is met by the support of the body, but if it passes outside, then there is nothing to resist it, and the body will fall over. The centre of

gravity gets a chance of going lower, which it always wants to do, and takes it. We can try the same experiment with any kind of body: with a round rod, or with a man cut out of flat wood, whose centre of gravity we can find by hanging him up from different points, as we did with the thin board. We can give the man a stand, no longer than his feet, to prevent him falling sideways. Then we shall find once more that as soon as the downward line through his centre of gravity falls outside his feet he will topple over.

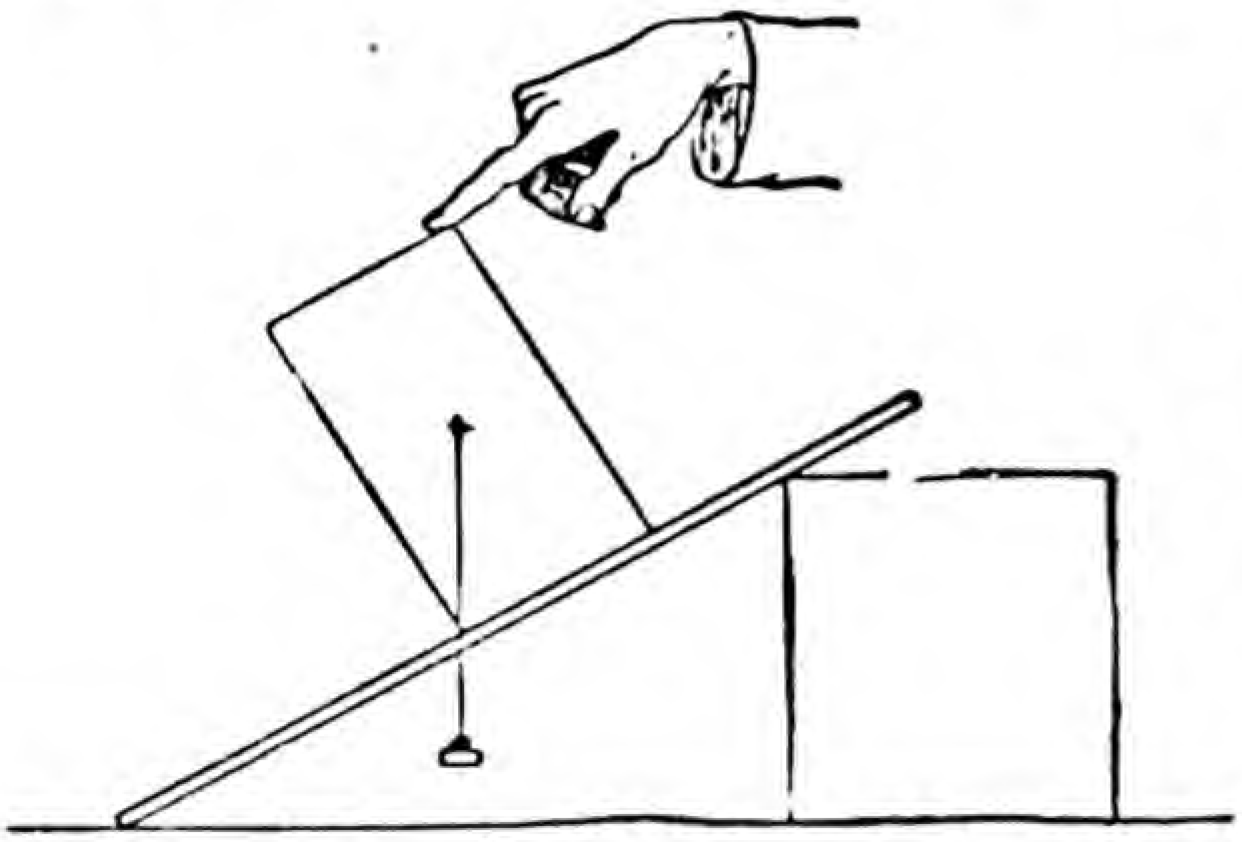


FIG. 53.—*To show that a block falls over when the vertical line through the centre of gravity falls outside the base.*

The centre of gravity of a man or boy with his arms at his sides is somewhere in the middle of the abdomen. You can test this by standing on one leg, and seeing what you have to do to keep upright. You will find that you either have to swing the body to one side, so as to bring your centre of gravity over the one foot, or to stretch out the arms to one side, which shifts the centre of gravity, by placing more of the body to one side of the central line than to the other. Another way to prevent the downward line through the centre of gravity

FIG. 54.—*Little Tich.*

falling outside the base is to make the base bigger. There used to be a music-hall comedian called Little Tich who wore boots with long wooden soles sticking out in front, and he could lean right forward without falling over, in a way that looked very ridiculous.

We can make the centre of gravity lie in unexpected places by using weights of lead or other heavy substances. The centre of gravity of a wooden ball is at the centre, for the ball is the same all round, and there is no reason why it should be more to one side than to the other. But if we conceal a leaden weight inside the ball, to one side, we arrange for the gravity pull to be stronger on that side than on the other, and the centre of gravity, the point where the result of the gravity pulls on all the parts of the ball acts, will also be shifted to one side. Such a ball will not roll true, for the centre of gravity is always seeking to go as low as the rolling of the ball will allow. The balls with which the game of bowls is played are loaded in this fashion, and the skill of the game lies in knowing how to make them roll where they are wanted. People who cheat at gambling also use dice which are loaded with a little weight to one side which makes that side come down more often than the others.

Tricks depending on the Centre of Gravity

There are some amusing toys which cannot be made to lie down: if they are pushed over they stand up again by themselves. One such toy is shown in the picture. The secret is that they have a base of lead, shaped as shown, with the result that the centre of gravity is lowest when the toy is standing up. The picture which shows it tilted over makes it clear that the centre of gravity has been raised, so that the toy will not stay in that position. If there were no

lead, the centre of gravity would be higher up in the toy, so that when the toy is laid on its side it would be lower than when the toy stands upright. The picture makes this clear.

If we can arrange things so that the centre of gravity falls directly *under* the point of support, a body will stay in that position. This is the secret of many toys. The wooden parrot that perches by itself has a weight in its tail, so that its centre of gravity is much lower than its claws: if it had a weight in its head, it would not perch. It must not surprise you that the centre of gravity is, as shown, actually outside any part of the parrot. Think of a ring. However you hang it, the downward line through the point of hanging will go through the centre of the ring, which is, however, outside the metal of the ring. If you want to make the ring balance in any position you can fix a wire across it (which will not alter the position of the centre of gravity if it is light enough), and you will find that the ring will balance on a point in the middle of the wire, showing that the centre of gravity is really there, in the middle of the ring. Again, clearly, the centre of gravity of a ball is at the centre, even if the ball is made hollow, for there is nothing to make it more to one side than the other. But when the ball is hollow, there is no part of the ball at the centre.

FIG. 55.—*When the old lady is pushed over she comes again to an upright position by herself. How the toy is made is shown on the right. With the leaden base actually used the centre of gravity is low, and the line through it falls inside the base. If the figure were all of wood, as on the extreme right, the centre of gravity would be much higher, and the line through it falls outside the base.*

Knowing what we do about the centre of gravity, we can perform many amusing tricks. One is to hang a pail of water, by means of a stick and a plank, on to one side of a table. Of course it will not hang in the position in Fig. 57 (*a*). But if the stick is used, as shown in Fig. 57 (*b*), to push the pail well to one side, so that its centre of gravity comes under the edge of the table, the whole thing will

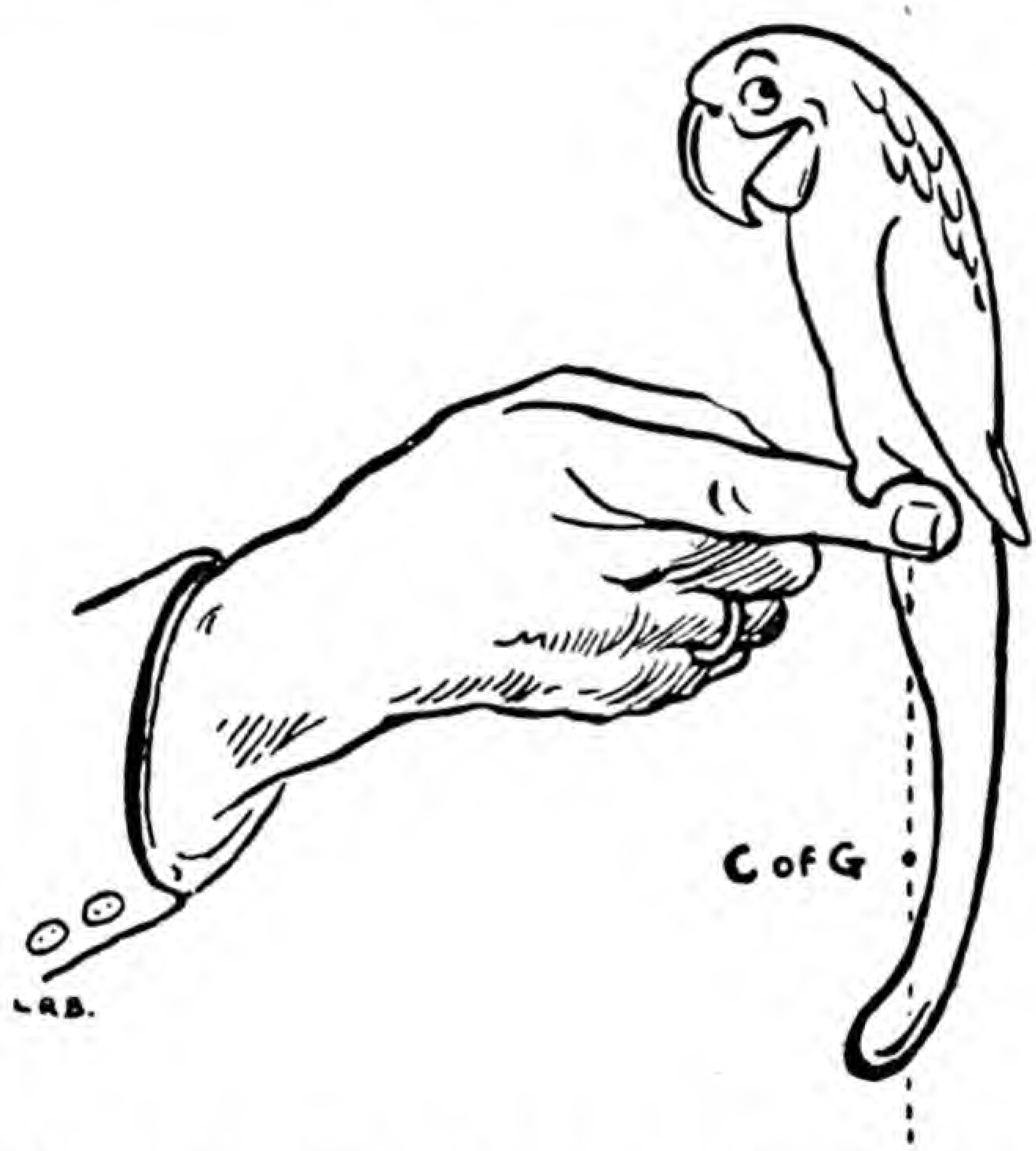


FIG. 56.—*The parrot that perches has a weight in its tail to make the centre of gravity lower than the claw.*

balance and can be made to swing backwards and forwards, but it will always come to rest with the centre of gravity directly under the point of support.

Another trick of the same kind is to make a penny stand on edge on the point of a needle. All you want is a cork and two table forks, or heavy skewers will do. The cork is cut and the penny is inserted as shown in Fig. 58, and the

two forks stuck in the cork like wings. The centre of gravity of the whole arrangement is then right outside the penny, at the point shown. Clearly, then, if we put the

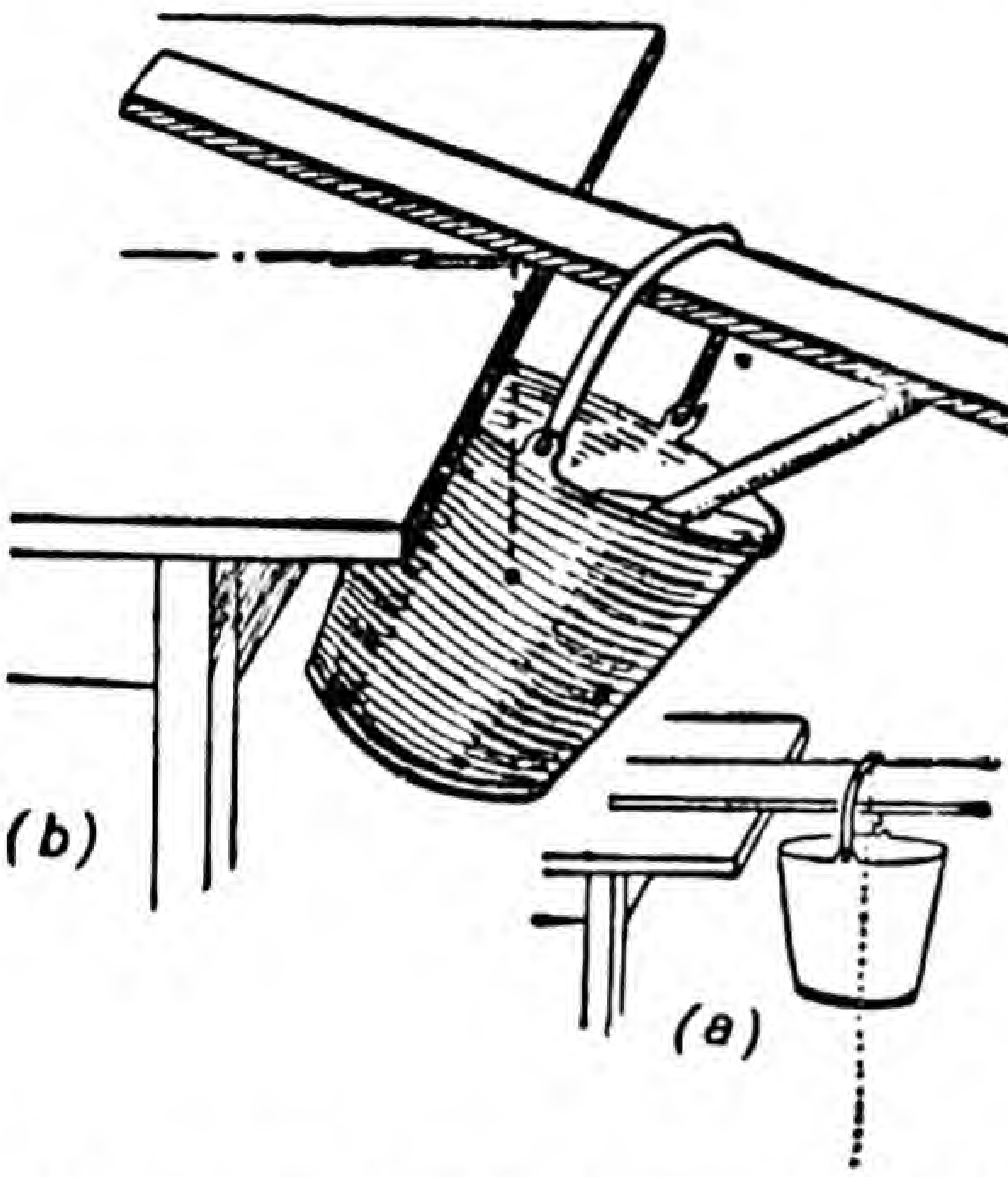


FIG. 57.—*How to hang a bucket of water on the edge of a table with a plank and a stick.*

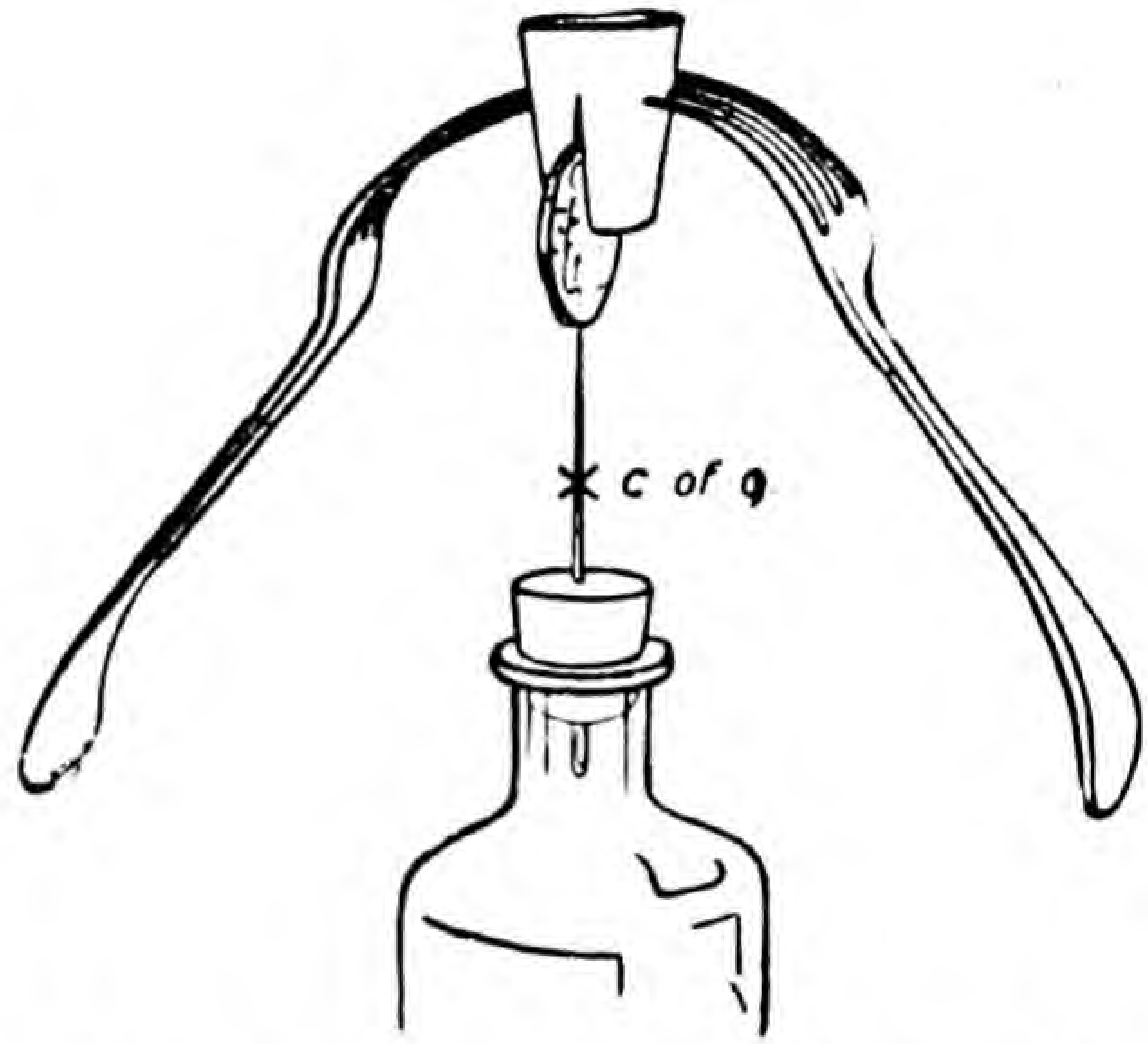


FIG. 58.—*Balancing a penny on the point of a needle.*

penny on a needle point the centre of gravity can get below the point of support, and the penny will balance. It is easy to prove that this happens. The penny can be rocked, but will always come back to the upright position.

Last of all, remembering that the centre of gravity always gets as low as it can, we can explain one more puzzle. If two pieces of wood, joined at one end and open at the other, like a **V**, are arranged so as to form a sloping runway, with the open ends higher than the point of the **V**, and a double cone, of brass or of wood, is placed at the lower end, it will appear to roll uphill. Actually the two

ends of the cone do roll in the uphill direction, but owing to the fact that the two parts of the runway are further and further apart as they go up, the centre of gravity of the

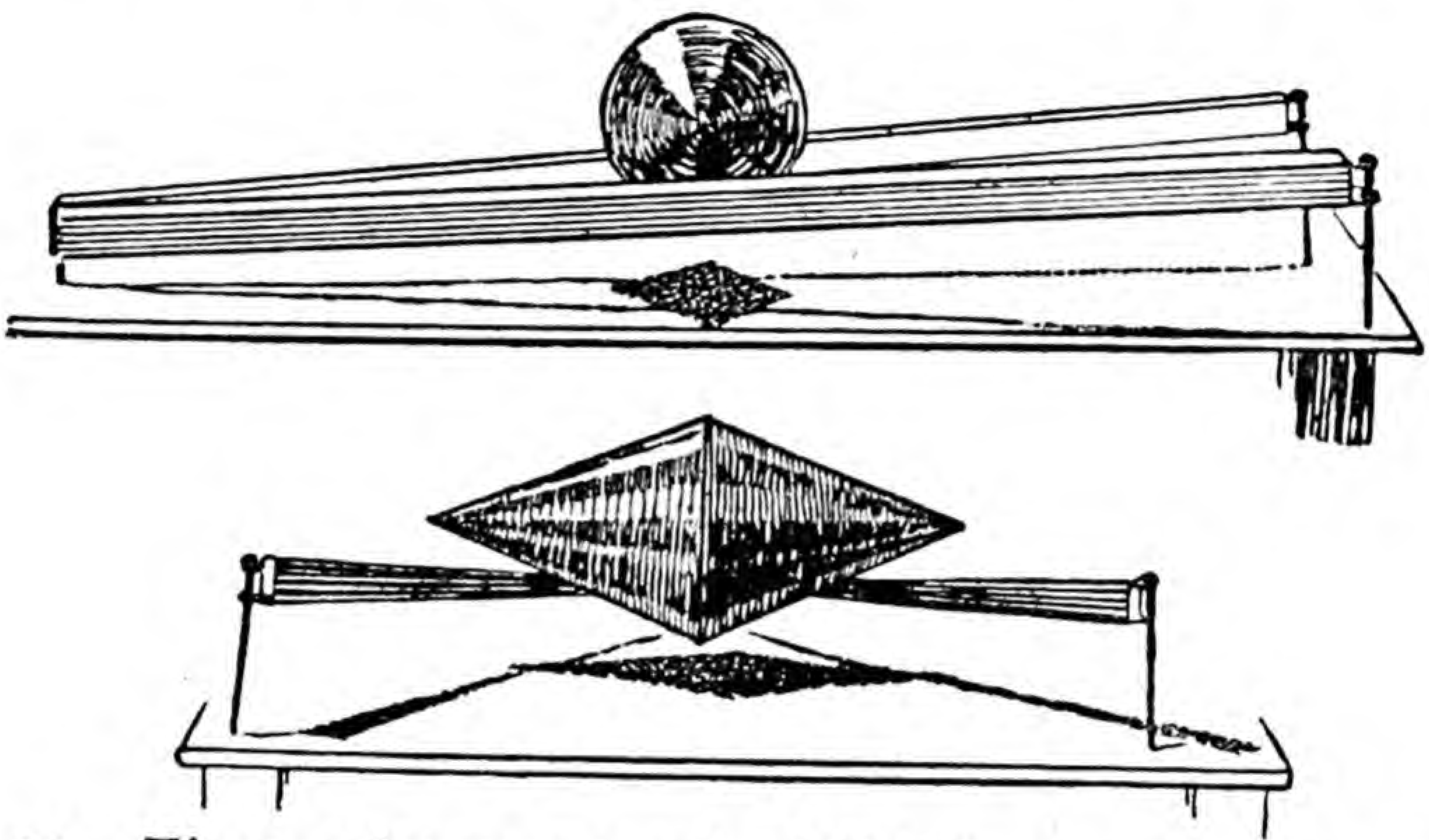


FIG. 59.—*The cone that seems to roll uphill. The upper picture shows the sideways view, with the cone rolling from left to right. The lower picture shows a front view as seen by somebody on the right of the upper picture, and helps to show that the centre of gravity really falls as the cone rolls.*

double cone really sinks. A look at the picture will make this clear. The centre of gravity goes downhill, as it must. The appearance of rolling uphill is only a trick.

CHAPTER IV

ENERGY

Heat, Light and Sound

SO far we have been talking about things which we can weigh on scales and measure with rulers. It is true that most gases cannot be seen, but they can be weighed, and moved from one bottle to another, as we have learnt. There are, however, plenty of interesting effects that do not occur in lumps, have no weight, and cannot be shut up in bottles. Light, for instance, by the help of which our eyes tell us what is going on—unless we have the terrible misfortune to be blind—is not a solid or a liquid or a gas: it is not a thing. We cannot buy a bottleful of light, take it home, and let it out. Heat also is not a thing. We can have hot things and cold things, but we cannot take the heat out and away from the thing, and keep it separately in a bottle. When we heat things at a flame we are not pouring anything into them: they weigh just the same hot as cold, if proper care is taken. The rays of the sun that warm us do not weigh anything and they do not consist of invisible gases, for they can come straight through a window pane. Sound, also, is not a thing that can be collected and weighed. When we put a record into a gramophone, we are not scraping sound off the disc. We are merely, by means of the grooves in the record, waggling the disc of the sound-box about in a way that makes sound. The violinist makes the strings of his violin shake quickly to and fro, and the sound comes from them, but nothing passes which we can collect or weigh.

Heat and light and sound are all agencies,[1] let us say (for it is best not to call them things), which can act upon things and produce effects in them. Light, for instance, can warm the things which it falls upon: if it is very strong, like sunlight, it can warm them considerably. It can make the chemical changes in a photographic plate that enable us to take photographs. It makes plants green: if we cover up a plant, or grow it in a cellar, it is white. Light does things to our eyes which enable us to see. Heat can boil water and so work steam engines, and it can melt metals. Sound can make things quiver, although it has to be very loud if this quivering is to be big enough to be easily seen. However, that is how gramophone records are made. The sounds of the music which is being recorded are made to push a thin sheet of mica or some other substance backwards and forwards in tune with the quiverings of the notes, and this sheet moves a steel point which cuts into the sides of a spiral groove in a soft wax disc, from which the records are afterwards made. There is much more to learn about sound and the way in which records make sounds when put on the gramophone, but just now all that you need to notice is that sound can move things, even if only very light or bendable ones, and that the telephone and gramophone and talking pictures all begin with sounds pushing a very thin iron sheet backwards and forwards.

Heat, light, and sound cannot, then, be weighed or bottled, but they *do things*. This is why we called them agencies, because the Latin word *ago*, from which agency comes, means *I do*, and an agency simply means an affair which does something. (In business an agency is a man or branch who does something, or acts, for another

[1] The meaning of the word "agency" is explained below.

man or business.) The kind of action which heat, light, and sound have is, in the end, to make things move. You may think at first that light cannot move things, but it is light that actually provides the mighty forces that cause winds, even the terrible tempests that tear up trees. The light from the sun falls on the earth, and warms it more in some parts than others. Now warmth causes upward currents of air, and other air has to move in from the side to take the place of the air which rises. Winds are nothing but moving air, so that we can say that the sunlight really provides the force of the winds that can blow great ships over on one side, and throw down fences. Of course, the places where the winds occur and the time when they blow depends upon a great many things, as, for instance, the clouds which prevent the sun reaching the earth under them, and the sea, which is warmed by the light differently from the land, and so on.

In the last chapter we learnt that anything that pulls or pushes something so as to make it move is said to *do work*. Heat and light and sound can, then, all do work. Anything that is capable of doing work is said, in science, to have energy, just as we say a boy or girl is energetic if he or she does work. Heat and light and sound are, for this reason, called *forms of energy*. We may say that if by the help of any agent we can move things, in any way, then that agent has energy, and we know now that the energy may appear in different forms.

Transformations of Energy

There is another most important form of energy with which you are all very familiar, and that is electricity. You cannot weigh electricity, or get a bottleful of it—that is, of simply electricity and nothing else—although you can

get a glass jar of lead plates and chemicals that will produce electricity, and is called an electric accumulator. In this way electricity reminds us of heat. You can have a bag of coal which, when burnt, will produce heat, but you cannot have a bag of heat and nothing else. Electricity moves trains and machines of all kinds, so we must admit that it is another form of energy to add to our list.

Different forms of energy can be turned one into another. Heat can be used to work engines: all steam engines are really machines for turning heat energy into the energy of motion of the parts of the machine, which in their turn do the work required. This work may be to

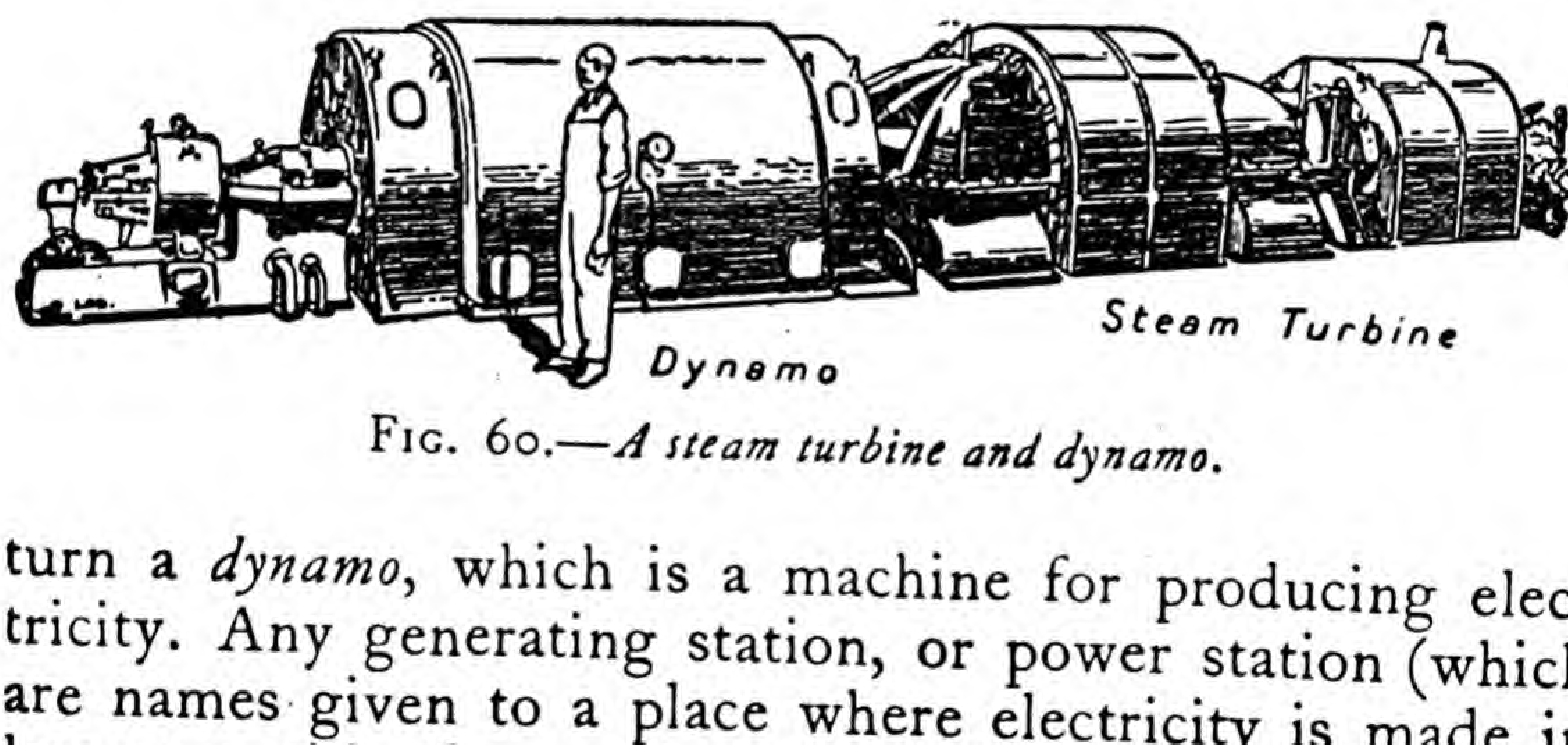


FIG. 60.—*A steam turbine and dynamo.*

turn a *dynamo*, which is a machine for producing electricity. Any generating station, or power station (which are names given to a place where electricity is made in large quantities for running railways or factories or supplying a large number of houses with electricity for domestic purposes), contains furnaces for burning coal, boilers for producing steam, engines, usually of the kind called turbines, worked by steam, and dynamos driven by the steam engines. It is really a place where the heat energy won by burning the coal is changed into electrical energy, and the engineer in charge will tell you that for every pound of coal he can reckon on getting just such a quan-

tity of electricity. With an efficient station the heat obtained from 1 lb. of coal produces enough electricity to light a 100-watt lamp[1] for seven and a half hours.

When we come to the ordinary electric lamp, which is simply a wire in a glass globe, we have another group of energy changes. The electricity passing through the wire makes it hot—that is, the electrical energy is changed back into heat energy. The hot wire gives out light—that is, part of the heat energy is changed into light energy. Unfortunately, no one knows how to make all the heat energy change into light energy, and the bulb gets very hot.

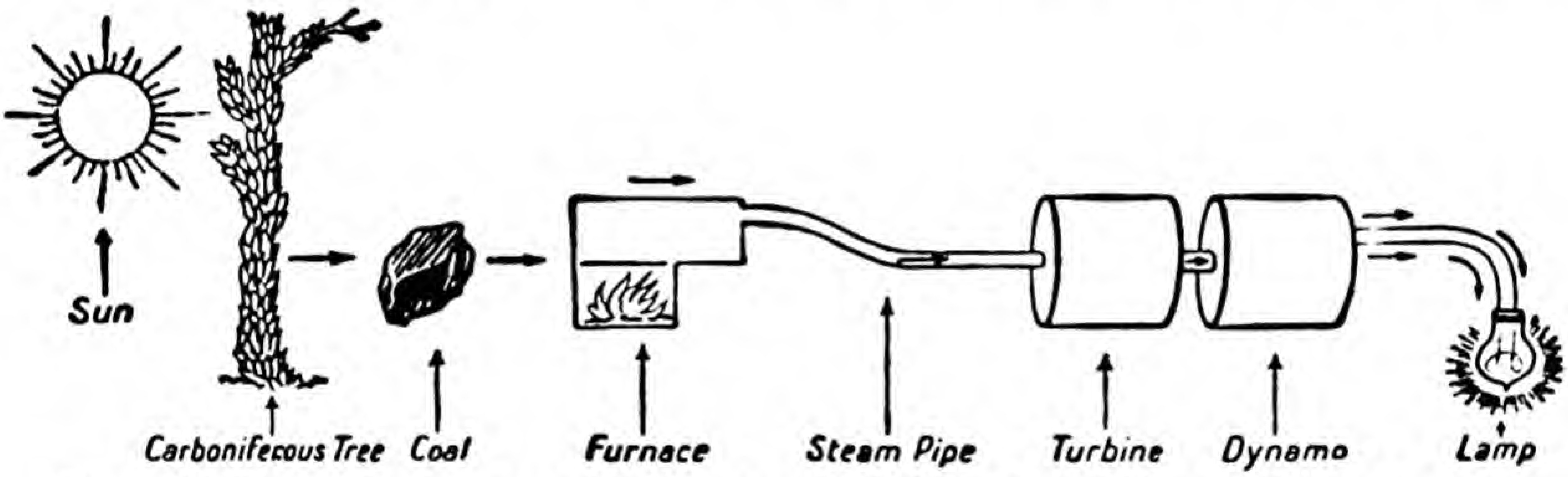


FIG. 61.—*The transformations of energy by which the sunlight of many thousands of years ago is turned into the electric light of today.*

Anyone who could make this heat, which is now wasted in warming up the bulb, turn into light, would be a millionaire several times over.

Now coal is the remains of old trees and vegetation which have been buried in the earth for many millions of years, and have changed in some strange way to the black stuff we all know. Trees cannot grow and develop without light: they need the light energy to help them build up their woody trunks and branches from the water and air with which they are supplied. To the making of every

[1] A 100-watt lamp should give nearly as much light as 200 candles.

piece of wood we see, and to the making of every piece of coal, which was once wood, a certain amount of light energy has gone. See, then, what a wonderful chain of energy changes we have. Some of the sun's light energy, sent out millions of years ago, is stored in the coal. The coal is burnt, and the energy stored in the coal becomes heat energy. The heat energy is turned into energy of movement of machines, by means of a steam engine, and that energy of movement is turned into electricity by a dynamo. The electricity goes through a fine wire in a lamp, and its energy becomes heat energy. Part of that heat energy is sent out as light. So, from the light of the sun, we have come back to light again, by a series of changes of forms of energy, or, as it is called, by a series of *Transformations of Energy*.

Heat and Work

Any steam engine gives us an example of heat being turned into work, or, putting it in other words, of heat energy being turned into mechanical energy. It is also possible to do the reverse of this—that is, to turn mechanical energy into heat energy. If you rub a piece of metal hard on a piece of wood, it gets hot, and the harder and the longer you rub it, the hotter it gets; the more work you do, the more heat you get. Every man who works at a lathe knows that if you press a steel tool against a piece of metal turning quickly the tool gets hot, and that if the metal is turning very fast indeed the tool gets very hot indeed. In fact, when lathe work is being done at high speed, it is necessary to keep oil or soapy water running over the tool to prevent it getting too hot, and melting at the edge. Part of the energy needed to run the lathe goes to make this heat. Again, when a railway train has been

running a long time, the axles are apt to get hot by long rubbing in their bearings. In fact, wherever things rub together, we get heat, and the more effort it needs to rub one over the other the more heat we get.

It always needs a certain amount of push or pull to move one thing past another against which it is pressing—for instance, to push a board over a flat concrete floor, to keep a wheel turning round, or to open a drawer. In the case of the wheel the metal of the axle rubs over the metal of the bearing as it turns, in the case of the drawer the wood of the drawer rubs over the wood of the strips called runners. There seems, then, to be a force acting against us in all these cases. This force, which acts as if trying to stop us moving one thing over another, is called the force of *friction*, which just means rubbing. Occasionally engineers are glad of it, as in the case of the friction clutch in a motor car, where, when two cones are brought together, friction prevents one slipping over the other, and makes the whole thing behave as one, which is what is wanted. Generally, however, engineers want to make the force of friction as small as possible, because it wastes some of the energy of their machines. It takes more work to move a railway wagon when there is much friction at the axles than when there is little, more work to push a piston in a cylinder when there is much friction than when there is little. This wasted energy, we know now, does not disappear completely, but turns into heat, and the bigger the friction forces, the more heat we get. Friction turns energy of motion, which we want to use to do work, into heat which we cannot use. This is very interesting, for it tells us that whenever we get a heating of moving parts by rubbing we are losing part of the energy of our machine—losing it, that is, in the form that we want it. We are really *ex-*

changing it for heat energy, which we do not want. The job of getting rid of rubbing forces and of getting rid of heating is one job, not two.

The engineer makes the friction forces as small as he can by various tricks. The one which you all know is called *lubrication*, and consists in putting oil of certain kinds, called lubricating oils, or greases of various kinds, or even other substances, such as graphite, on the surfaces which rub together. This makes it much easier for them to slide over one another, and, of course, the heating is made much smaller at the same time. Ball or roller bearings are another way of making a shaft or axle turn easily. The picture shows a roller bearing, such as is often used on railway coaches. The axle is supported on little rollers, which turn with far smaller rubbing forces than occur if the axle is simply passed through a hole.

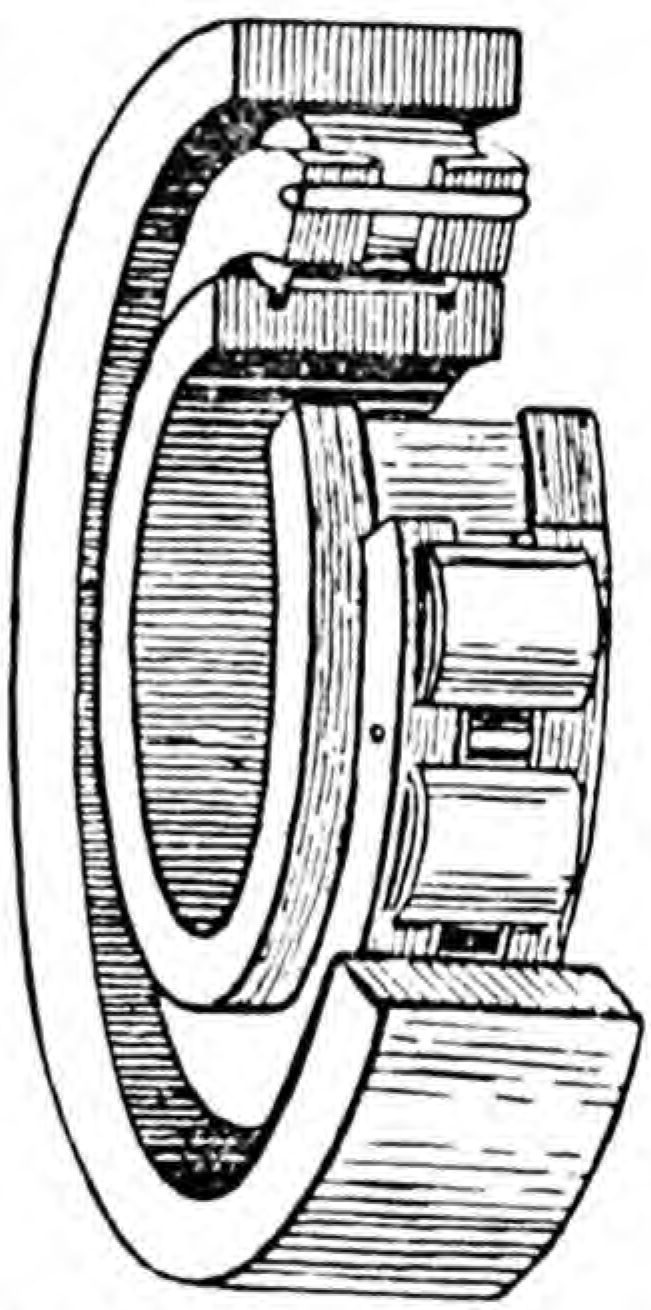


FIG. 62.—*A roller bearing with the front cut away to show the rollers. This makes the friction very small indeed.*

The heat that we can get by doing work can be actually used to light a fire. In some parts of the world the natives have a way of rubbing two sticks together so hard that they get hot enough to burst into flames. There is another interesting way of making work energy turn into heat energy. When air is squeezed up, as in a bicycle pump, you have to do work to squeeze it, and this work turns into heat. For instance, when air is quickly forced into a motor tyre by a pump, the air gets warm. We can use this fact to produce a

flame in the following way. We take a strong glass tube with a closely fitting piston and put at the bottom, on cotton-wool, a few drops of a liquid[1] whose vapour easily catches fire. If the piston is now suddenly forced down, the air becomes so hot that the liquid flashes into flame, as can be seen through the tube.

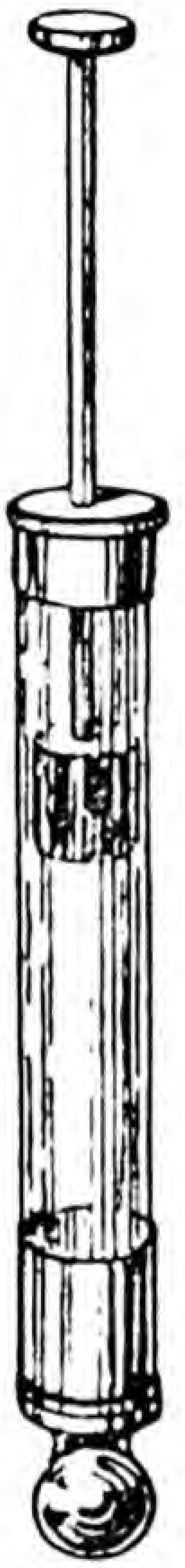


FIG. 63.—*The inflammable vapour in the glass cylinder is fired by the heat produced when the air is suddenly compressed.*

KINETIC AND POTENTIAL ENERGY

Let us think of some of the common forms of energy which are used in things around us. A body can have energy because it is moving, like the flywheel of

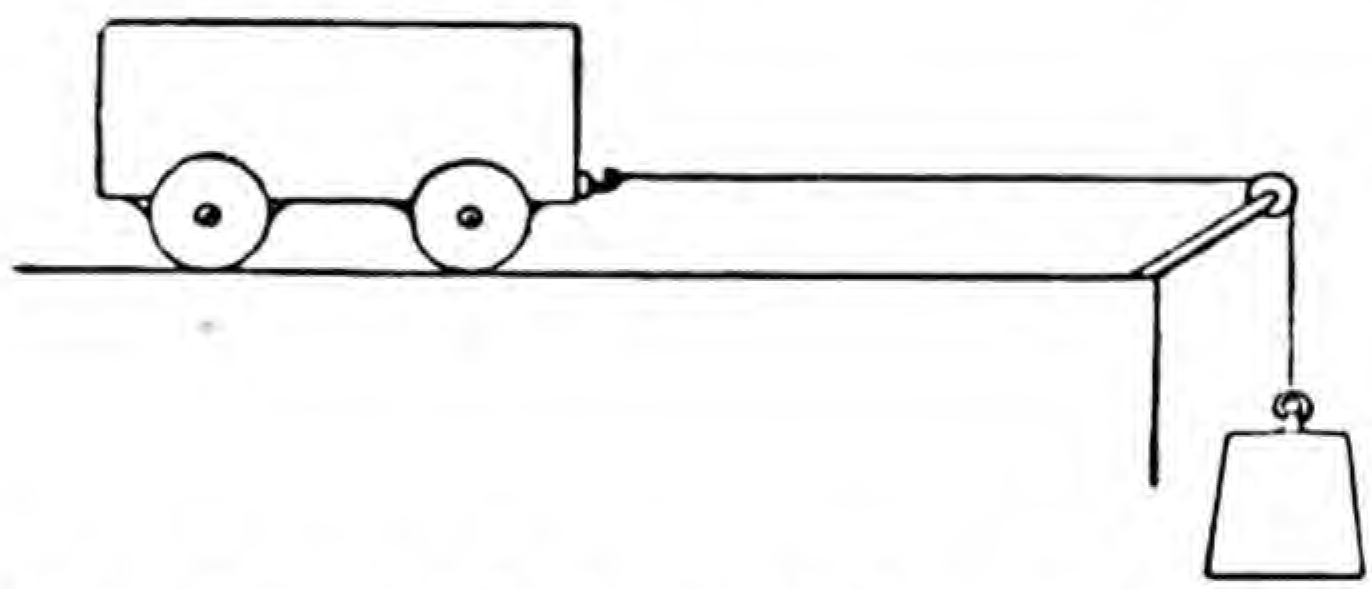


FIG. 64.—*A falling weight pulling a car.*

an engine. This energy of motion is called *kinetic* energy, from a Greek word meaning motion; we meet the same Greek word in *kinematograph*, as it should be spelt (or cinematograph, as it is usually spelt), which means motion picture. A body can also have energy of position. If we lift a weight on to a high shelf, and tie a rope to it passing over a pulley, or round a roller, then if the weight be pushed off the edge of the shelf it will pull up another

[1] The liquid called carbon disulphide is best.

weight, or pull along a car, as shown in the picture. The weight when in its high position has the chance of doing work, or we can say that it has energy of position. This energy is called *potential* energy, signifying that it is energy that it is possible to bring into action, the word "potential" meaning possible, as distinct from actual. (Thus we can say that a man is a potential boxer, meaning that though he is not actually a boxer, perhaps through lack of teaching, he is the kind of man who could be turned into a boxer.) Any body at rest, which can be released so as to produce work, has potential energy. A wound-up spring has potential energy, because although it is still so long as it is kept back by a catch, say, as soon as the catch is released the spring begins to uncoil, and can do work, like moving a gramophone record round, or turning the hands of a clock. The old grandfather clock was worked by weights which were wound up to a high position, where they had potential energy, from which they gradually fell, losing their energy of position, which was used to run the clock. When we wind any clock, we put into it quickly a quantity of potential energy which afterwards comes out very slowly in working the clock, the escapement, as it is called, of the clock preventing it from coming out fast. It is like giving a man a month's wages in advance, which he afterwards spends slowly.

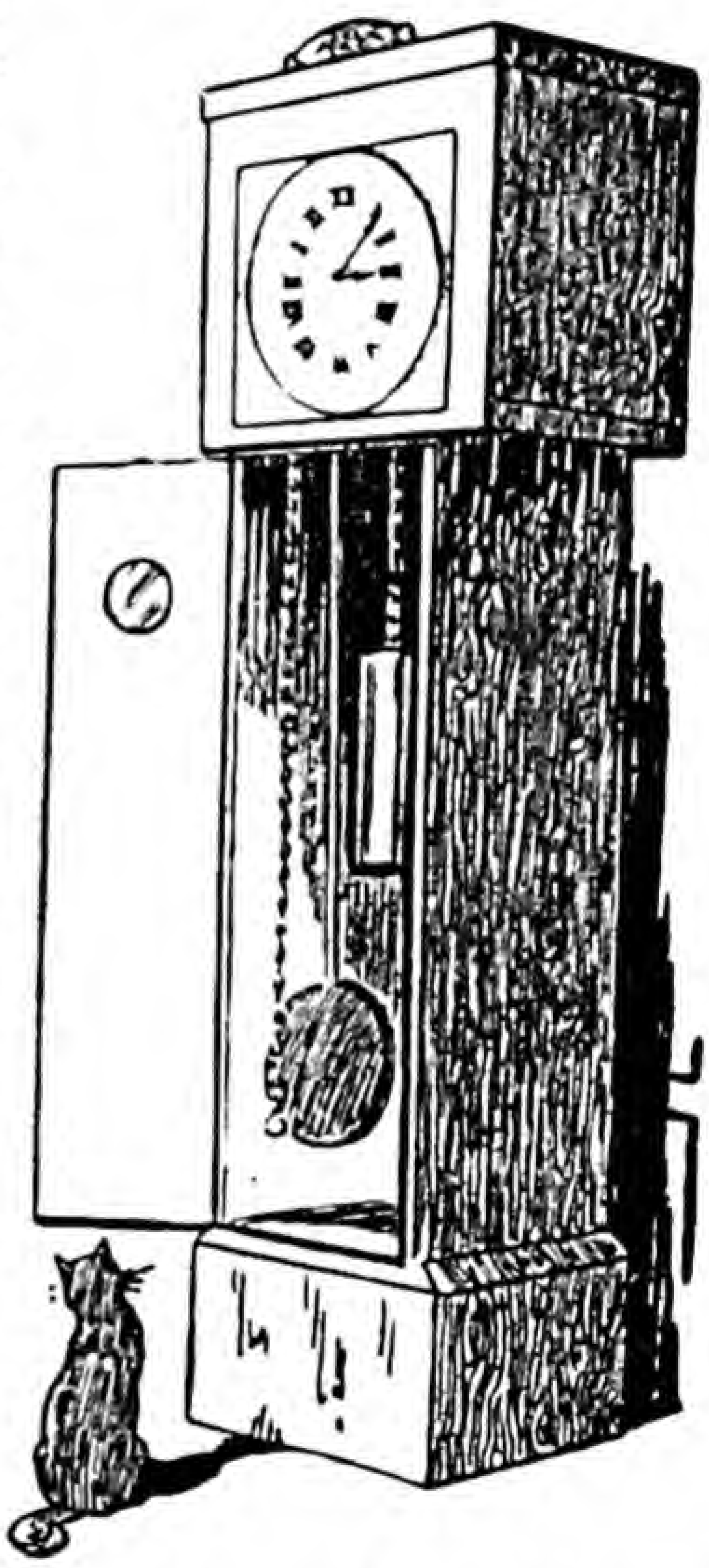


FIG. 65.—*A grandfather clock. The weight that works it is seen on the right. The clock is about half run down.*

Light as a Form of Energy

We have already talked about heat as a form of energy which can either produce work or be produced by work. Light has been mentioned as a form of energy, and it has been pointed out that light can produce heat. If we want to make this very plain we can let the sun's rays fall on a magnifying glass, or burning glass, as it is sometimes

Fig. 66.—*A burning glass which brings the sun's rays together in a small spot called the focus, which is very hot.*

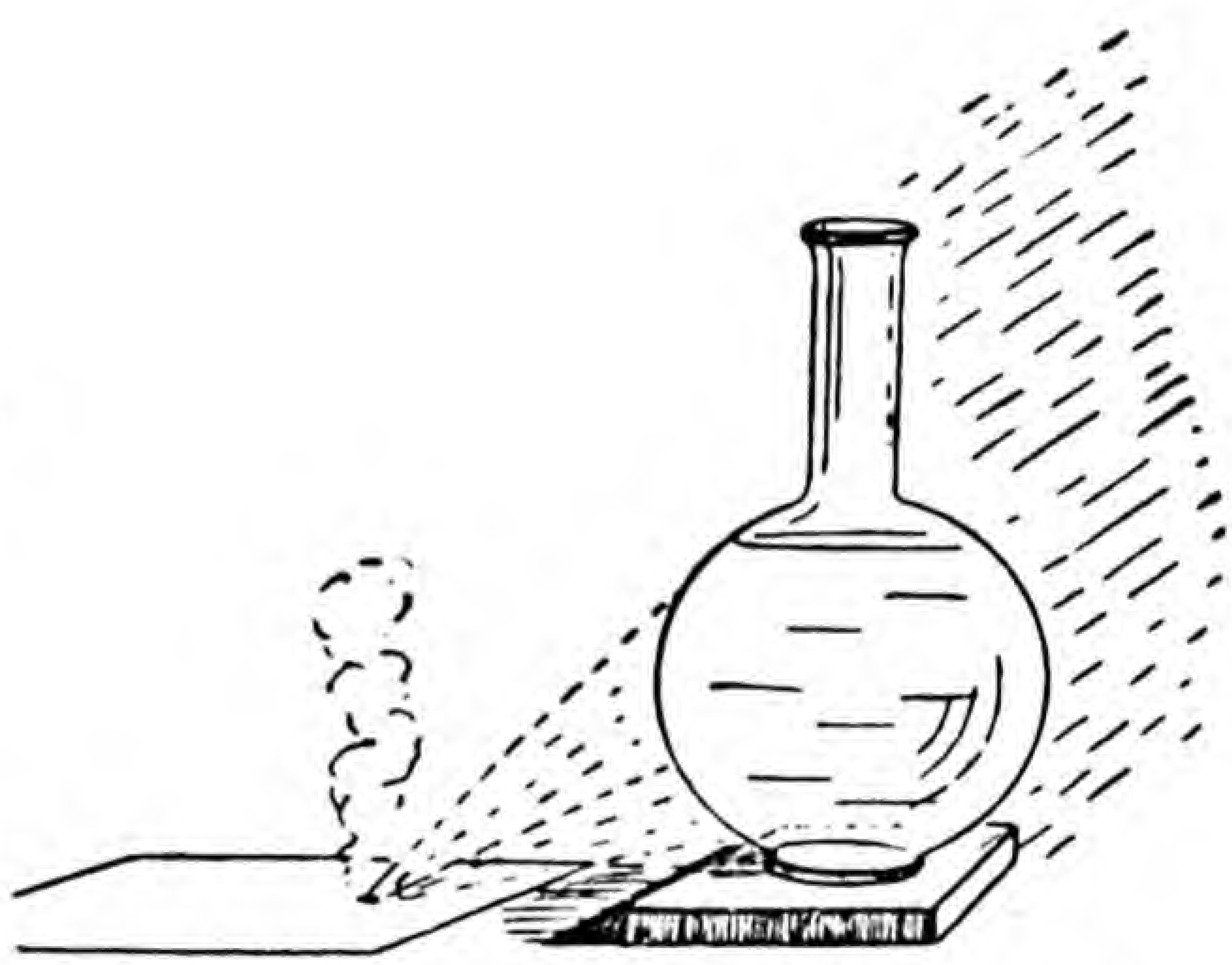


Fig. 67.—*A flask of water acting as a burning glass.*

called, which does not really make the sun's rays any hotter, but brings all the rays that fall on it together in a much smaller space, just as a roof with gutters brings all the rain that falls on it into one pipe, where the water makes quite a stream. The place where the rays are brought together is so hot that we cannot bear it on the back of our hand: in fact, if a piece of paper is placed there, and the

day is clear, the paper will smoulder and catch fire. Fires have been caused before now by the sun falling on a round water bottle placed in a window. The bottle acts as a burning glass, and brings the sun's rays falling on it into a little round patch, and if pieces of paper happen to be there, a serious blaze may soon be started. This shows

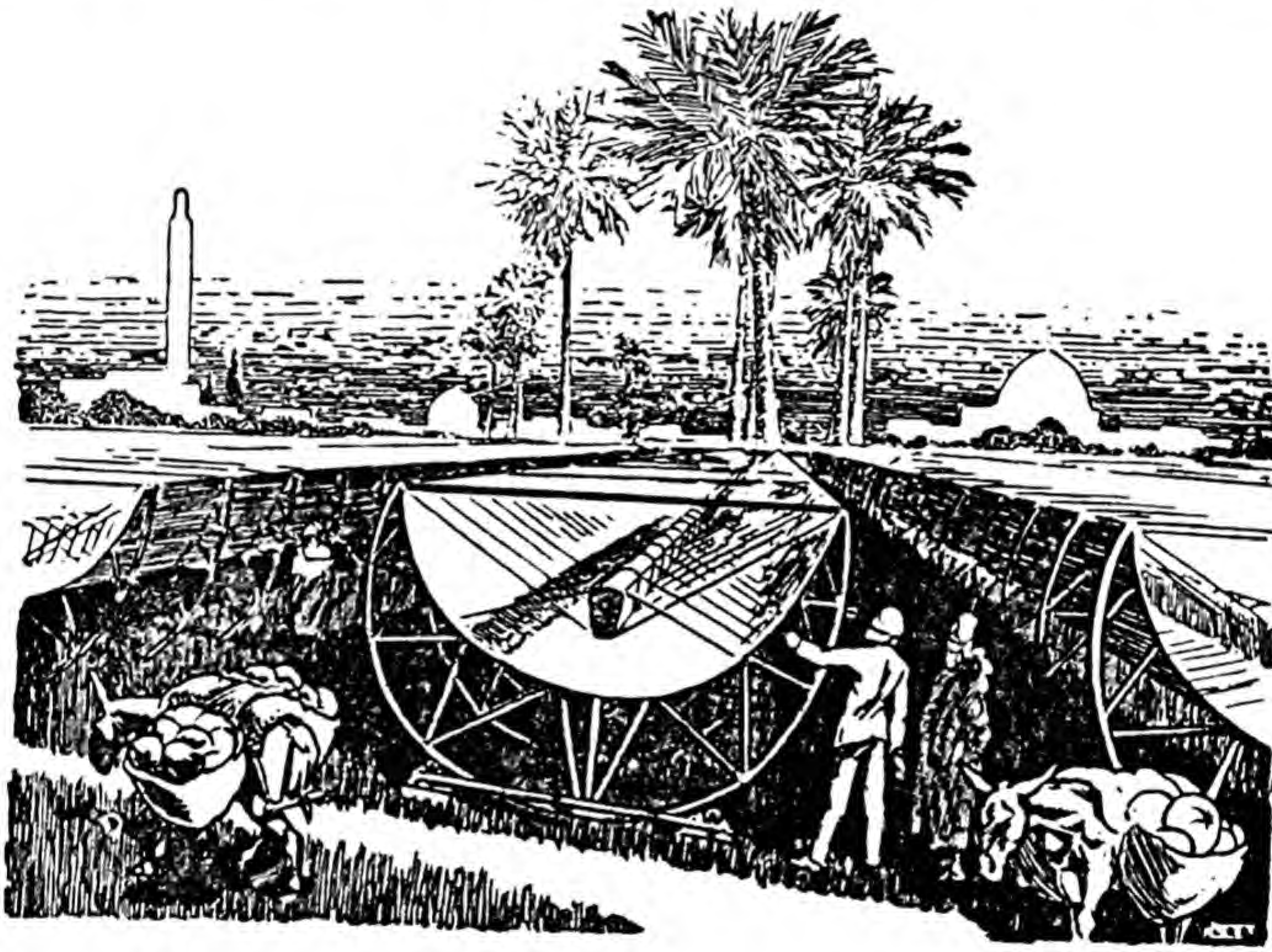


FIG. 68.—*The sun engine in Egypt. The boilers are long tubes suspended in curved reflectors, which have to be tilted so as to face the sun.*

that the light can be turned into heat. In Egypt, where there are long times of uninterrupted sunlight, a steam engine exists which is run by the sun's heat. The rays are brought together by big mirrors of special shape on to the boilers, in the shape of long tubes, and about 60 horse power is produced, but the boilers take up a great deal of land. This shows us clearly that light is a form of energy,

since we can get horse power from it, even if it needs a great quantity of light to produce a little work. Most of the heat of the sun's rays is in the form of visible light, although there are some rays in it, too, which cannot be seen but which do bring heat with them.

A simple experiment shows that it really is the rays from the sun that do the heating. If two tins are exposed to the sun, one blackened on the outside with soot and grease, or with the paint called Bates's black, and the other bright, the blackened tin will get hotter than the other one. If both are the same size, and both filled with cold water from the same tap, it will be found that the water in the blackened tin gets warm much the quicker. It is best to use a thermometer to show this, and not to rely on the feeling of the hand. Now the bright tin clearly reflects most of the light, which means that most of the light which falls on the tin goes away again: little is absorbed. The black tin, however, sends back very little of the light, which is another way of saying that nearly all the light which falls on the tin is absorbed. In the case where the light is absorbed we get heating, because the energy that disappears as light is turned into heat: in the case where the light is nearly all reflected there is naturally very little left behind to be turned into heat.

Fig. 69.—*Eastern buildings which are whitewashed to make them cool.*

The fact that black things absorb light and turn it into

heat, while bright things or white things throw back again nearly all the light that falls on them, is very important in many ways. In hot climates people always wear white clothes for coolness, because they do not absorb the rays of the sun. Anyone who wears a black coat on a hot day will find himself much hotter than if he wears a white coat of a similar material. In the East houses are nearly always made of white material or whitewashed, to keep them as cool as possible.

Sources of Energy

Since no motion of trains or motor cars or machines and no light can be produced without a supply of energy, we see that energy is the one thing that we must have if the conveniences of our present-day life are to go on. Let us consider what our sources of energy are. In the first place, anything that can burn is a source of heat energy. When anything, say a piece of wood, is burnt, it changes from being a piece of wood into being certain gases, which rise from the fire, and some ash, which is left behind and will not burn. Later on you will learn more about burning, but it will be sufficient for us here to bear in mind that the wood does not vanish into nothing when burnt, but is altered; of the things into which it is altered only the ash is visible, the others being invisible gases, which can be distinguished from ordinary air by chemical tests. First, then, we have wood and air, and after the chemical change[1] which we call burning, we have ash and gases—*and* a supply of energy. We get hold of the energy because of the chemical change: the supply of energy and the

[1] Whenever things change their nature the change is really a chemical one: the change need not be done in glass flasks or test tubes with acids for it to be chemistry.

change of the wood and air are both parts of one process, just as when you put a penny in the slot of an automatic machine, and get matches or chocolate, the putting in of the penny and the supply of the goods go together. We say, then, that when a thing is burnt the heat is a result of a change of chemical energy.

We can get heat from other chemical changes. If sulphuric acid is mixed with water, which should be done carefully by dropping the acid slowly into the water, and stirring well, the mixture gets very hot. If an acid, like hydrochloric acid, is mixed with a substance like soda, heat is also produced. Some chemical changes have the opposite result, and lead to cold. For instance, if ordinary hypo, such as is used by photographers, is dissolved in water, the water goes very cold. We learn from all these things, then, that chemical changes, especially burning, can be sources of heat energy.

All kinds of things can be burnt. The most valuable fuel found in England is coal. Another valuable fuel is oil, still another is petrol. Oil is used in all kinds of ways: it can be sprayed into furnaces on ships, and burned there, instead of coal, to produce steam, or it can be burnt inside the cylinders of certain kinds of engines, where it is fired by compression—that is, by squeezing up the air in the cylinder, just as we did in the experiment illustrated in Fig. 63. Such engines are called Diesel engines, or semi-Diesel engines, and are very much used nowadays to drive ships, especially cargo ships. Petrol, as everybody knows, is burnt inside the cylinders in motor-car engines. Although the burning takes place very quickly, more like an explosion than the quiet burning of coal in a grate, it is nevertheless a burning. Oil is not found in England in sufficient quantities to make it worth while

trying to get it, but oil can be made from coal nowadays, and it may possibly turn out to be wise to change some of our coal into oil and other things. In olden times wood was very much used for fuel, and in the early days of the locomotive in America wood was burnt under the boiler,

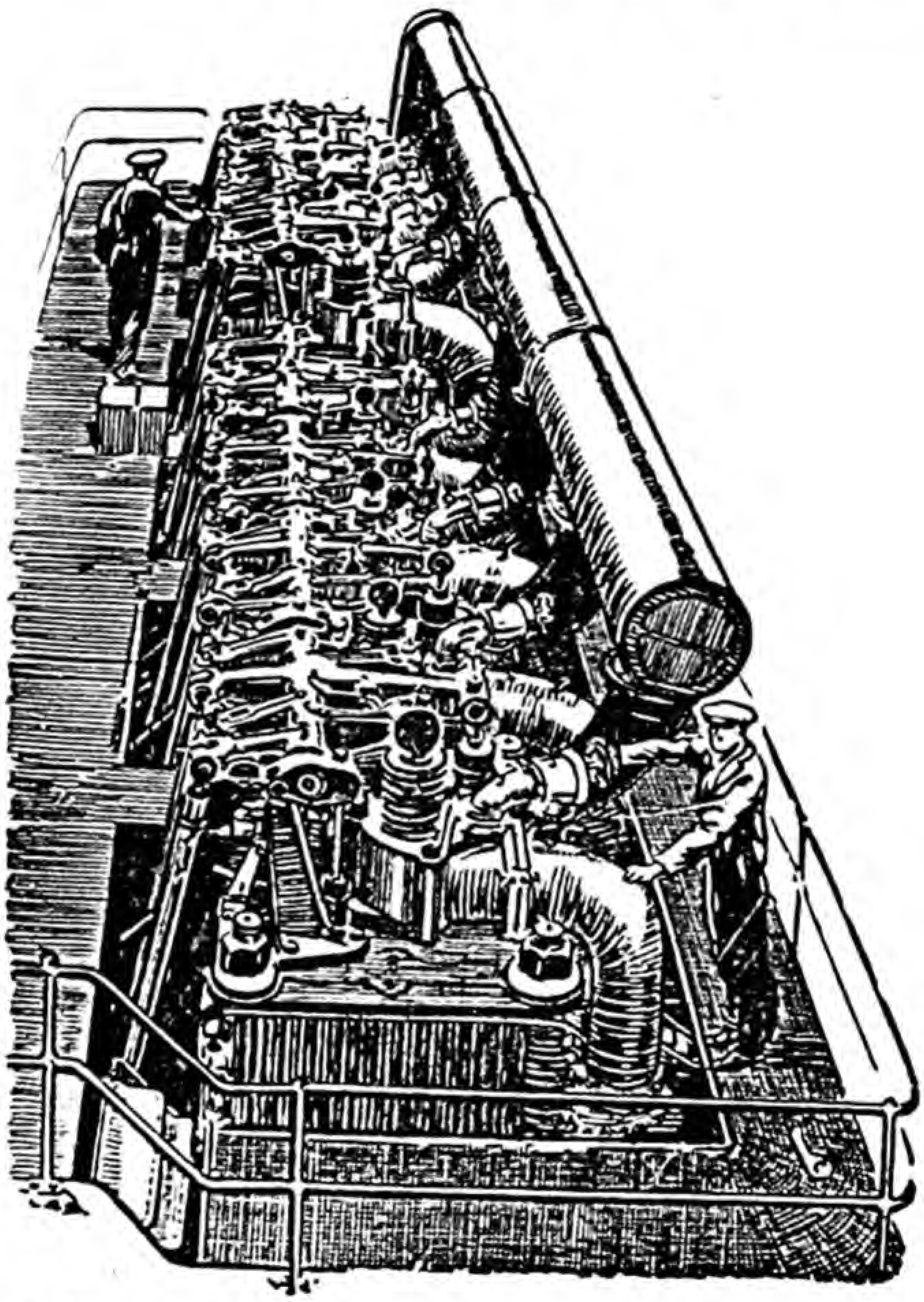


FIG. 70.—*The cylinder heads of a big marine Diesel engine, which burns oil in the cylinders themselves.*

because of the scarcity of coal; wood is still used on most African railways. Anything at all that will burn is a source of energy, but some things are very much more convenient than others.

In Nature we already have things which are moving, and whose energy of motion can be used to drive our

engines. These things are moving air and moving water, or, putting it another way, winds and rivers. We have already mentioned that winds are really produced by the sun's light, which is turned into heat where it falls on land or sea, and so causes air currents. Rivers are also made by the sun. This seems extraordinary, but this is how it happens. The sun's heat makes some of the water of the sea turn into vapour, or evaporate, as it is called. This water in the form of gas rises and forms the clouds. From the clouds rain falls upon the land, and running down from hills and mountains forms streams and rivers. Thus sea water goes up to the clouds (leaving, of course, all the salt behind it in the sea), falls on the land, forms rivers, and runs back to the sea again, the sun providing the energy to keep this merry-go-round going.

FIG. 71.—*A Dutch windmill which puts the energy of the wind to work.*

The wind will drive windmills, which are not as much used now as they were in times gone by, because the wind cannot be trusted to blow all the time, or just when wanted. Still, many small windmills are used for pumping water on farms, and such like. Rivers and streams and waterfalls can be made to turn water wheels, by which the energy of motion of the water is turned into energy of

motion of machines. The water goes into the water wheel quicker than it comes out: it loses energy of motion, the wheel gains it. Little use is made of water power in England, because we do not have many swift rivers, but in other countries, particularly in the mountainous parts of France and Norway and Switzerland, where there are

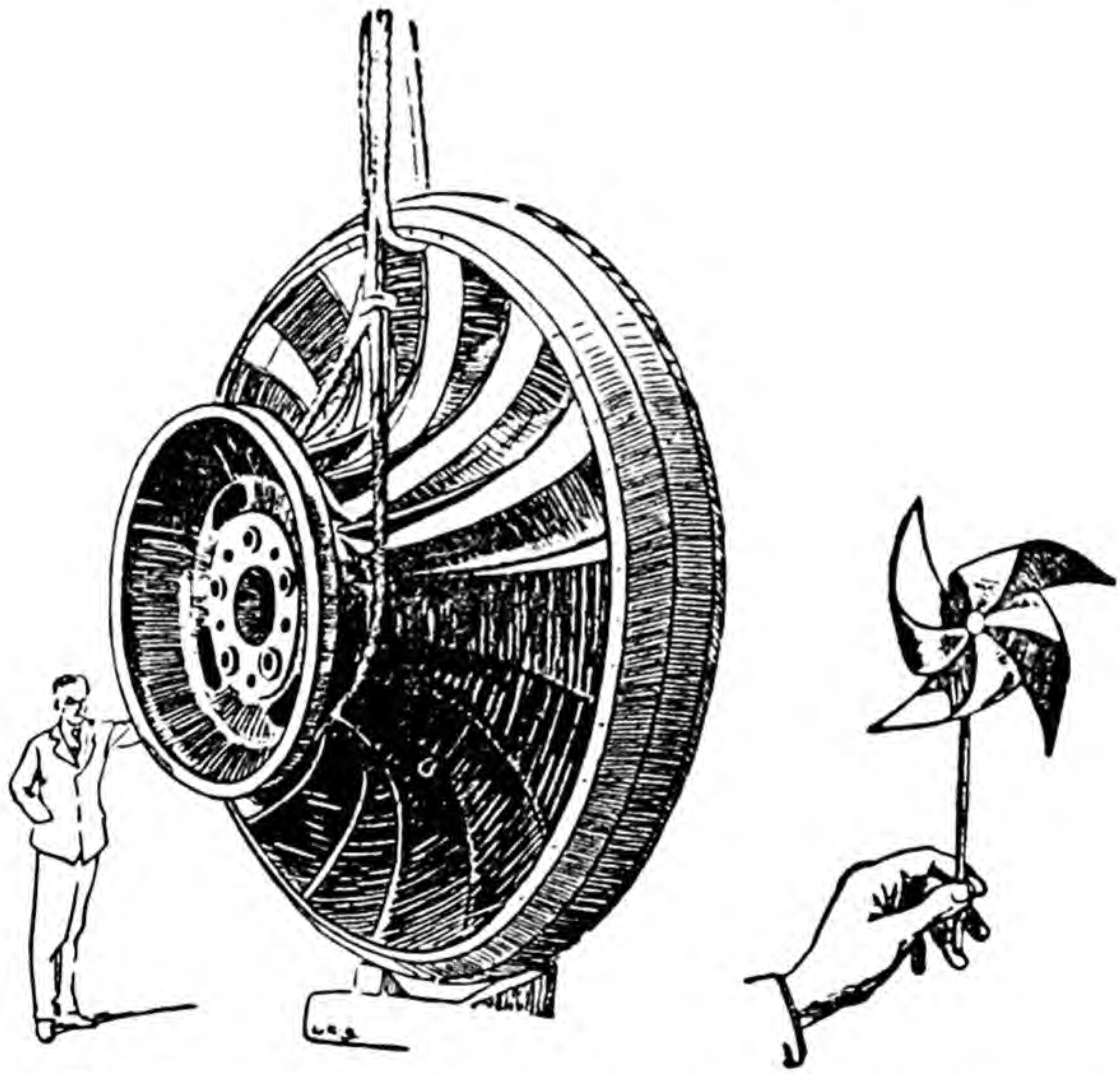


FIG. 72.—*The runner of a high-speed water turbine, which gives about* 6,000 *horse power with an* 11*-foot head of water. It acts on the same principle as the toy paper windmill shown on the right.*

rushing streams and rivers, large and complicated water wheels, called water turbines, are driven. The energy supplied by these wheels is used to drive dynamos and produce electricity, with the result that in Switzerland there is electric light in every little village, to be had at a very cheap rate. In England we have to burn coal to raise steam

to drive the steam turbines to turn the dynamos, a process which costs much more. Because of the way in which they take the place of fuel the French call torrents and swift streams and waterfalls "white coal."

At Niagara Falls, Canada gets 450,000 horse power by making the rushing water turn turbines, and America gets another 560,000 horse power, over a million horse power in all. This would require about 500 tons of coal *per hour* to produce by steam turbines. If you think of more than eighty men going into a power station *every minute*, each carrying a 2-hundredweight sack of coal (which is what would be required to obtain the same power), you can form an idea of the immense value of the water power of Niagara.

The Travels of Energy

The power created by water turbines or steam turbines is turned, by dynamos, into electricity, which is then sent through wires to do its work. It may go a long way; the power from Niagara, for instance, is, some of it, used as far off as 200 miles away. This reminds us in a very striking way that energy can travel. The electricity travels through the wires; the wires do not travel, but merely guide the energy. The light energy from the sun, which, as we have seen, is the first origin of our energy supply, travels through the air. It travels just as well where there is no air, for the air is a kind of overcoat round the earth, and does not exist far away from the surface. For nearly all the 93,000,000 miles from the sun to the earth light is travelling through complete emptiness. Light energy not only travels: it travels exceedingly fast, at the astonishing rate of 186,000 miles in a second. The waves of wireless telegraphy and of broadcasting also travel through com-

plete emptiness, and at the same very great speed as light. The speed at which electricity travels along wires and cables is also very high, but cannot be quite so great. How big it is depends upon the construction and size of the cable and upon other things, in a very mixed-up way.

Sound is another form of energy which can travel along, but sound cannot pass where there is nothing at all, as light can. Sound can go through solids, like the earth or an iron pipe; or liquids, like water; or gases, like air. The sounds that reach our ears in the ordinary way come through the air. If we are bathing in the sea and there is a steamship in the distance, we shall find that by putting our head under the water we plainly hear the sound of her screw or paddle wheel, when we cannot hear it with our heads up in the air. This shows the passage of sound through sea water. Everybody knows how in stories of adventure the hero puts his ear to the ground to listen for horses in the distance, because the sound of the hoofs travels plainly through the earth. Or we can put our ear to a wall, and get somebody—as far off as possible—to hit the wall with a stick, which will be easily heard.

Sound travels very much more slowly than light, as you can easily prove by watching a man chopping, or a boy batting, from a long way off. You will see the blow before you hear the sound of it: the vision of the man moving comes by light. If a gun is a mile off you will see the flash about five seconds before you hear the bang, for sound travels about 1,100 feet in a second.

Energy, then, can not only be made to travel short distances by the shafts and belts used in machinery, but it can also be sent through long distances as light or sound or electricity. Electricity is a form of energy which is easily produced and easily turned back into mechanical

energy by electric motors, after it has travelled great distances along wires. This is one of the things which makes it so valuable to us. The energy can be produced at some big convenient station, and then sent out along wires in small or large quantities to the places where it is required, and then turned into light or heat or engineering work cleanly and safely. We have mentioned that some of the energy from Niagara is, for instance, sent two hundred miles before being used, while in every big town the energy for the electric light and heat in houses is made at one or two, or a few, big stations, from which it travels out.

We can take one more example of the conversion of energy. Sound cannot travel where no air is, so that, however loud a sound was produced on the earth, people in the moon—if there were any—could not possibly hear it, for between the moon and the earth lies absolute emptiness. We could, however, turn the sound into wireless messages on the earth, as is done for broadcasting, and send out the wireless messages. These messages could travel through empty space to the moon, and could then be turned back into sound, supposing that there was air to carry it anywhere in the moon. Thus by changing the form of the energy we could talk to the man in the moon, if he existed, although he could never hear us shout, however much noise we made.

CHAPTER V

AIR

The Ocean of the Air

IT may seem more difficult at first to find out things about the air which surrounds us and which we breathe than to find out about water and metals and things which we can see. Although, however, we cannot see the air, we can see many things which it does. Wind is only air that is moving, and we can see branches and leaves moved by the wind. The wind turns weather-cocks, and in some parts of the country we can see small windmills for pumping water being driven by the moving air. Air has, then, sufficient substance to be able to push things when it moves.

Another thing which shows us that air has substance is the fact that it serves to hold up birds and aeroplanes. There must clearly be something quite substantial there for birds to be able to mount so quickly just by pushing on it with their wings; for the screw of an aeroplane to be able to catch hold of it sufficiently firmly to pull the aeroplane along; and for the wings of the aeroplane to be carried by it, with all the load they bear. Birds and aeroplanes, however, can only stay up if they move through the air, and make, as it were, a wind of their own.

Airships, on the other hand, can actually float in the air, just as balloons can. They can stay up in the air just as a motionless fish can stay floating in the water. We can, in

fact, think of the air as a kind of very thin invisible ocean that lies everywhere on top of earth and sea, and in which we move about, as divers walking on the bottom move about in the sea. We cannot breathe in the sea ocean, but can breathe in the air ocean; fishes can breathe in the sea ocean, but not in the air ocean. It does not seem absurd, then, to speak of the ocean of the air. The winds can then be called air currents, just as the streamings of water in the sea are called ocean currents.

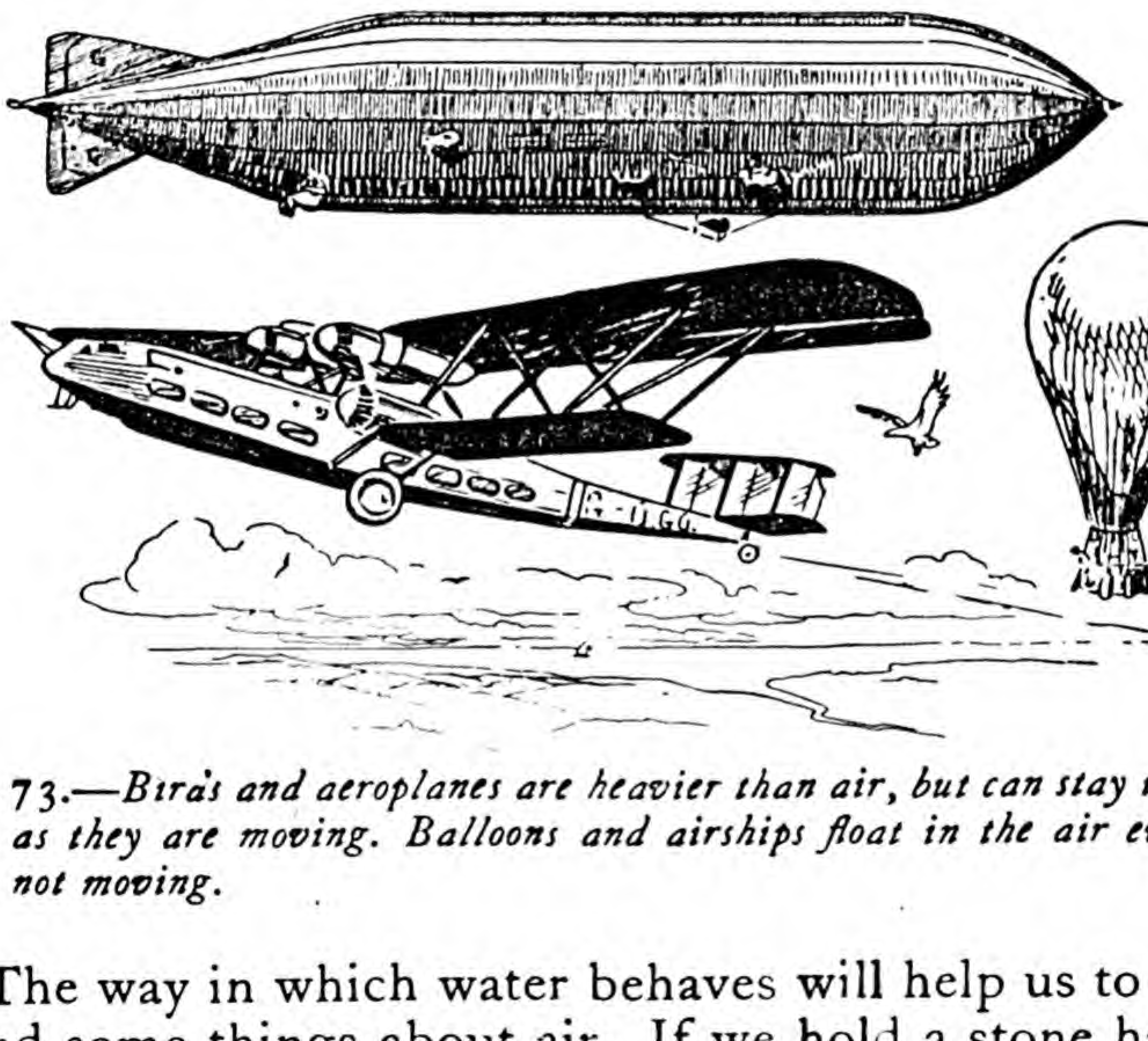


FIG. 73.—*Birds and aeroplanes are heavier than air, but can stay up as long as they are moving. Balloons and airships float in the air even when not moving.*

The way in which water behaves will help us to understand some things about air. If we hold a stone half-way between the bottom and the surface in a bath of water, or a pond, and let go, it will sink until it reaches the bottom. If we hold a cork in the same position and let go, it will rise until it reaches the top. This is because a stone is heavier than a piece of water the same size as the stone—

that is, it is heavier than the water whose place it takes. A cork, however, is lighter than the water whose place it takes, and it rises. For the same reason, if we hold a little corked bottle quite full of oil under water, and pull out the cork, the oil will rise to the top of the water: oil is lighter than water. If we can find something with exactly the same weight as water it will float about under the surface, but it is very difficult just to hit the right weight. Some kinds of wax have about the required weight. Or we can take a piece of wood, and gradually weight it by winding pieces of wire round it until it just swims under the water. (It is best to soak the wood in hot wax before this experiment, or it will swell while in the water, and make things more difficult.)

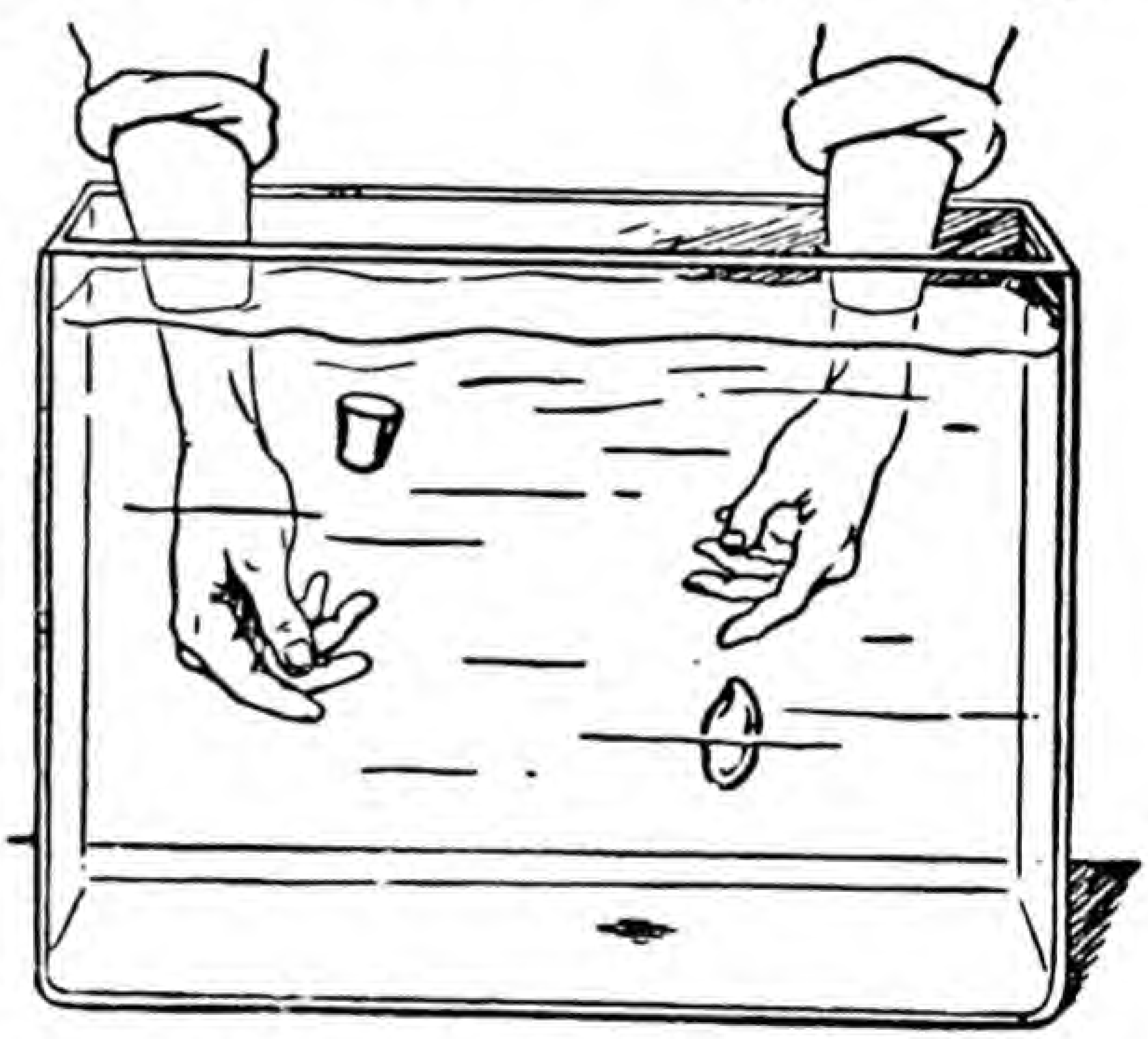


FIG. 74.—*A stone let go under the water falls, a cork let go under the water rises.*

Now let us consider the air. If we let go of something that is heavier than air, say a cushion, it will fall, but if, like a balloon or an airship, it weighs less than the air in a bag of the same size, it will float up like a cork through water. In time, however, it will stop going up; it will not go on rising until it gets to the top of the atmosphere. This is because the air becomes thinner and thinner the higher up we go. People who climb high mountains know very well that the air changes as they ascend: near the top it takes them some time before they can get used

to breathing the thin air. While, then, the balloon may weigh less than air at the surface of the earth it will weigh more than the thin air five miles up, say, and somewhere in between the surface and five miles up its weight will exactly equal the weight of the air. It is possible to make a balloon or airship because there is the gas called hydrogen which is very much lighter than air, so that a very large bag filled with it will not only float up, in spite of the weight of the bag, but can carry a load with it.

Air, then, gets lighter and lighter as we go higher, but water weighs very, very nearly the same, whether we consider it at the bottom of the ocean or at the surface. In spite of this difference between the water ocean and the air ocean it gives us the right idea if we think of a balloon going up as a cork floats up through water. It tells us, for instance, that we must not expect a rubber balloon to go up if it is filled with air. For it to rise we must fill it with something lighter than air, such as ordinary lighting gas, or coal gas, as it is called, which, although heavier than hydrogen, is much lighter than air.

The Weight of the Air

We have spoken of the weight of air. Does air have weight then? Certainly, and this is a very important fact. How can we show this? Not by weighing a bladder first full of air, and then empty; we shall find no difference if we do this, and we could not expect to find a difference. Think of the water again. If we hold a bladder under water it will weigh very little. Now suppose that we fill it full of water: it will weigh many pounds *if we weigh it in air*, but if it is under water it will still weigh hardly anything, as you can imagine, for the water now holds it up. In fact, we can balance the full bladder

against the empty one, as shown in the picture. We cannot, then, weigh the air in a bladder surrounded by air. But suppose, instead of a bladder, which changes its size, we take a glass or metal vessel, which is always the same size, so that the outside air always acts on it in the same way, and put different amounts of air in it, we shall find that we get different weights. One way to show this is to use a glass bulb which can be closed with a tap. The air can be pumped out with a kind of pump made for the purpose. The vessel is then weighed without any air in it, and after that the tap is opened, and air allowed in. The vessel is then weighed again, and will be found to weigh more. The difference will not be very big: the air in a vessel that holds a quart only weighs about one-twentieth part of an ounce —that is, about as much as a threepenny bit. An ordinary room, however, holds a great many gallons of air, so that

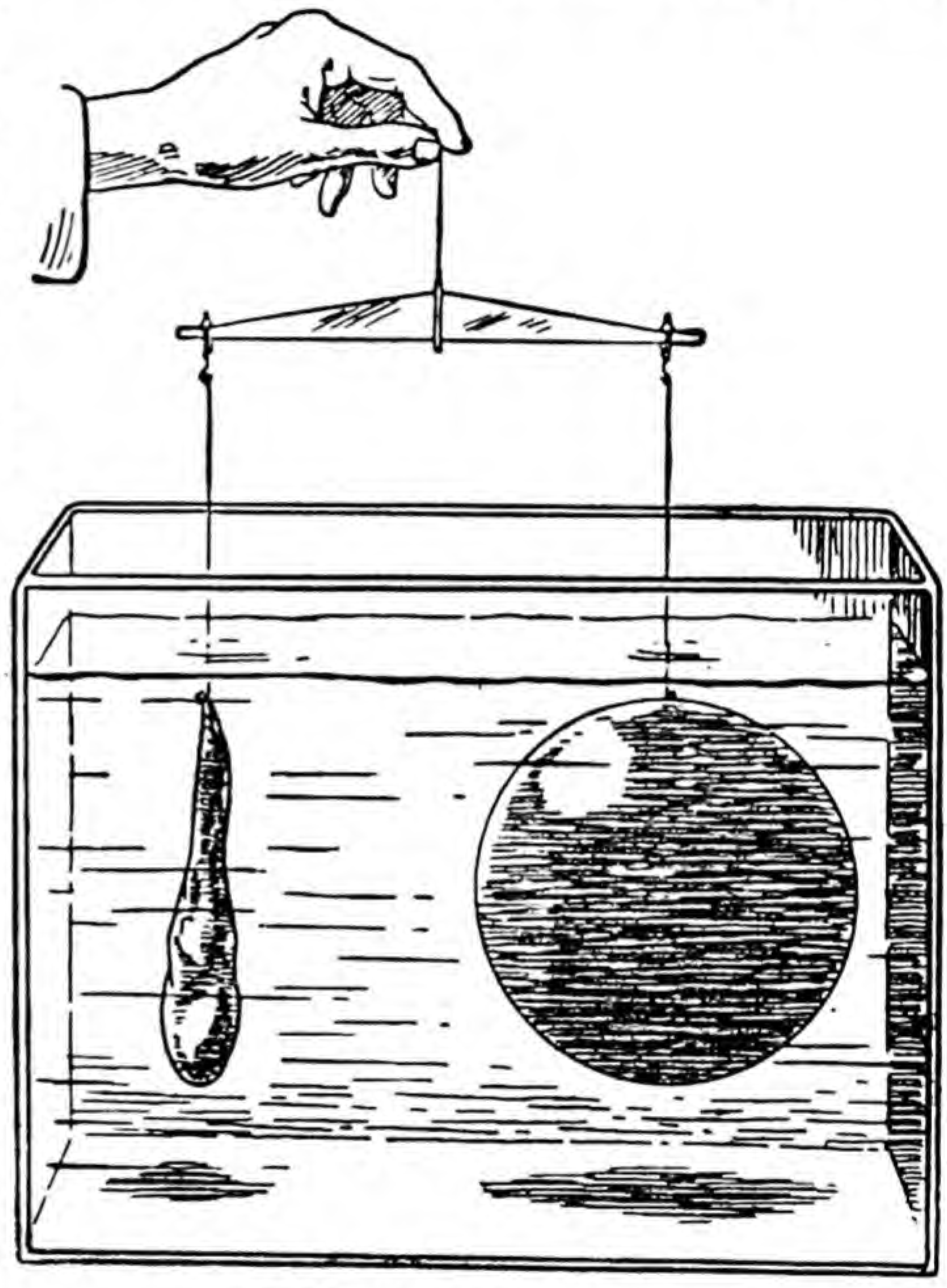


FIG. 75.—*A bladder full of water* (*right*) *and a bladder containing very little water* (*left*) *weigh exactly the same if they are both immersed in water.* (*Care must be taken to have no air in either bladder.*)

the air in a schoolroom 30 feet long by 20 feet wide by 11 feet tall weighs about 500 lbs. This is surprising to most people. It means that if we can make a bag as big as the room and fill it with some gas that will keep it blown out, and that if the whole thing, bag and gas, weighs less

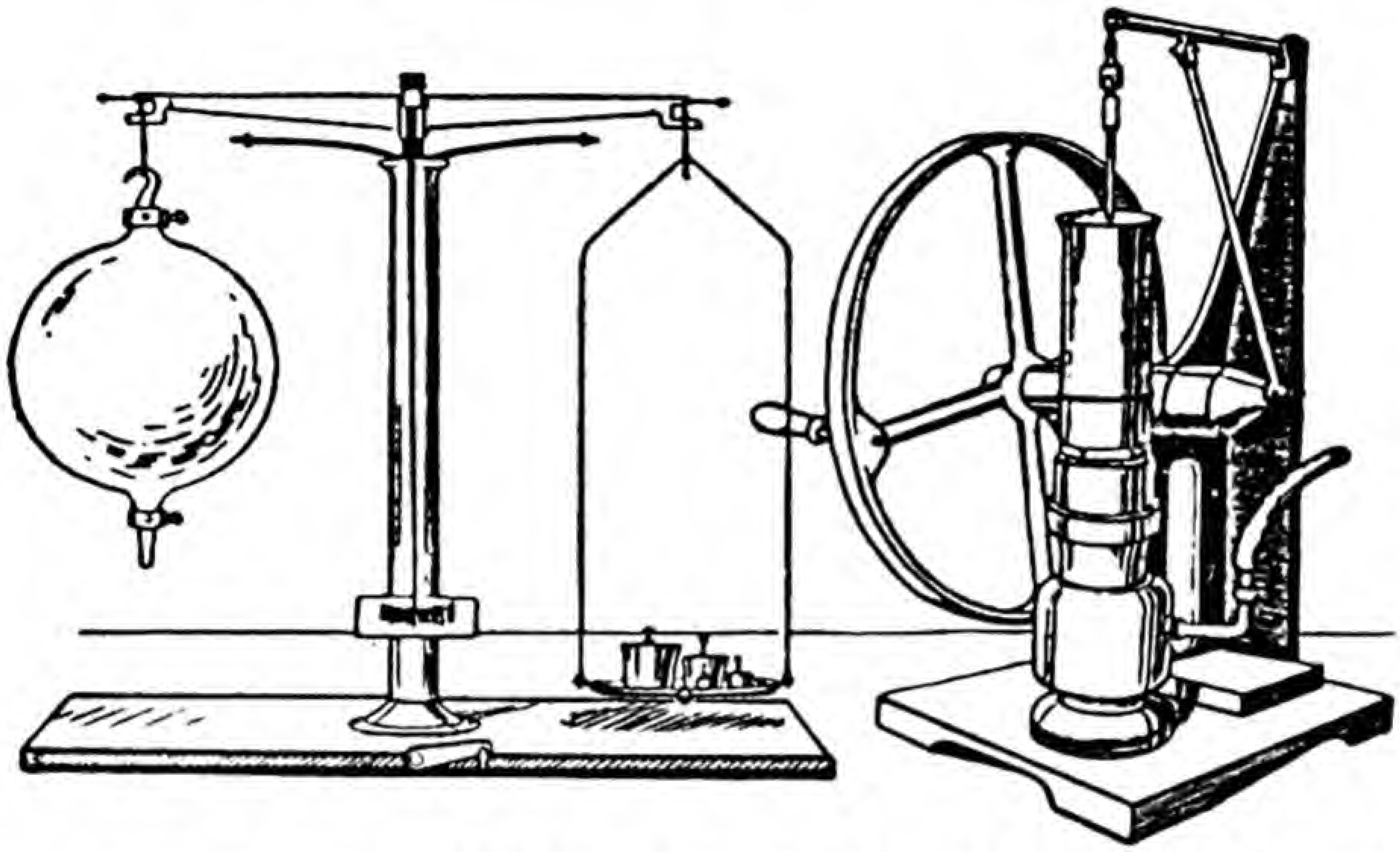


FIG. 76.—*Weighing air. The pump which is used for removing the air from the glass globe is shown on the right.*

than 500 lbs., it will float up, because it will be lighter than air. If it only weighs 450 lbs. it will just be able to take up a load of 50 lbs. with it.

The Pressure of the Air

When we were talking of the difference between a liquid and a gas we said that while liquids, like water, can only be squeezed smaller by very big pressures, and even then there is very little change in size, gases, like air, can be easily pushed into a smaller space. We say that gases are compressible, which means that they can be compressed, and compressed simply means "pressed together."

A gas balloon, in fact, is something like a rubber sponge: the harder you squeeze the sponge the smaller it gets and the more it presses against your fingers trying to get back to its old size.

Let us consider the pumping up of a motor car tyre. The pump consists of a cylinder with a tube leading from the lower end, to which the tyre can be attached. In the cylinder runs a piston, consisting of a cup-shaped leather, C, supported behind by a brass disc, D. When the piston is pushed down the pressure of the squeezed air forces the edges of the cup against the walls of the cylinder, so that an air-tight fit is made, and the air in the cylinder is forced into the tyre. This continues until the piston reaches the bottom of the cylinder. When it is pulled upwards the pressure is released, and the valve on the tyre closes. There is now nothing to force the edges of the cup on to the walls, and the air goes past the leather into the cylinder, which is thus filled ready for the next stroke. At every stroke of the pump, then, the cylinder is filled with air and the whole of that air is pushed into the tyre. As the pumping is continued it becomes harder and harder to push in the piston: we say that the pressure of the air in the tyre gets greater and greater. If the tyre and the pump and our arms were strong enough we could go on pumping in more and more air, and making the pressure higher and higher until it became enormous.

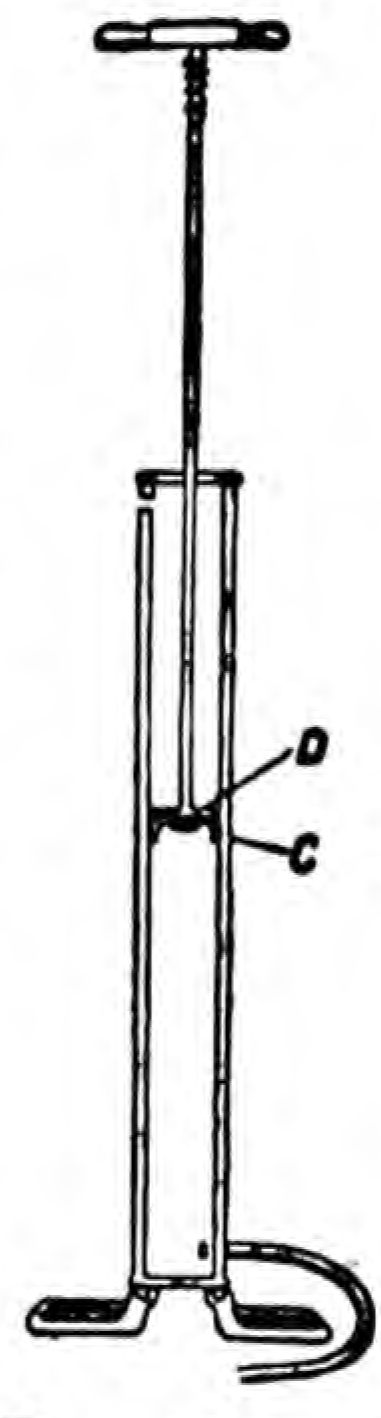


FIG. 77.—*A tyre pump.*

The weight of the air in any vessel or any room of a particular size must depend, then, upon what the pressure of the air is.

Suppose that we have a steel bottle, provided with a strong tap instead of a stopper, of the kind shown in the picture. Such bottles are made for holding carbon dioxide gas, which is used for preparing soda-water and the other bubbly drinks which are usually called mineral waters, although they have no minerals in them. The air which is in a bottle of about the size shown will, when the tap is open, weigh just about 1 ounce. Yet by using a pump driven by an engine it is easy to squeeze in so much extra air that it will weigh 7 pounds. We then say that the bottle is full of compressed air. If we talk of what the air in any particular space weighs, then, we ought really to say something about the pressure. When it was said that the air in a room of a certain size weighed about 500 lbs. it was understood that the air was not compressed, but was at just the ordinary pressure.

FIG. 78.—*A steel bottle, or gas cylinder, as used for holding compressed carbon dioxide.*

It may seem very strange to talk of the air around us in an ordinary room, or in the open, for that matter, as being at a pressure, for, someone might say, there is nothing to squeeze it, and it is not under pressure at all. It is true that there are no pumps pushing it, but it is under pressure all the same. Let us think of what the atmosphere is. We have called it an ocean of air, a layer of air many miles thick which is like a coat all round the

earth, and we have also seen that air has weight, and that air can be squeezed up, like rubber sponges. Suppose that a great wall were built of those rubber sponges, made in the shapes of bricks, which are so widely sold nowadays. The weight of the sponges of the upper rows pressing on those of the lower rows would squeeze them up, and the lower the row the more would be the weight of the sponges on top of it, and the flatter it would be squeezed. It is the same with the air. That part of it which is just near the surface of the earth has to bear the weight of all the rest of the atmosphere, and is therefore under quite a large pressure. If we go up half a mile the air pressure is nearly one-tenth less than it is at the surface: if we go up three and a half miles the air pressure is only a half of that at the surface of the earth. If we were to take a large bottle three and a half miles up, open it, and then put the stopper in, wax it over so that it was quite air-tight, and bring it down again, we should find that it had only half the weight of air in it that the same bottle would have if opened and closed again at the earth surface. In the same way, a man who takes a deep breath at a height of three and a half miles up only draws half as much air into his lungs as he does if he takes a deep breath on the low ground. Mount Everest is five and a half miles high, and one of the great difficulties of the heroic men who have tried to get to the top—and have actually reached a height of over five and

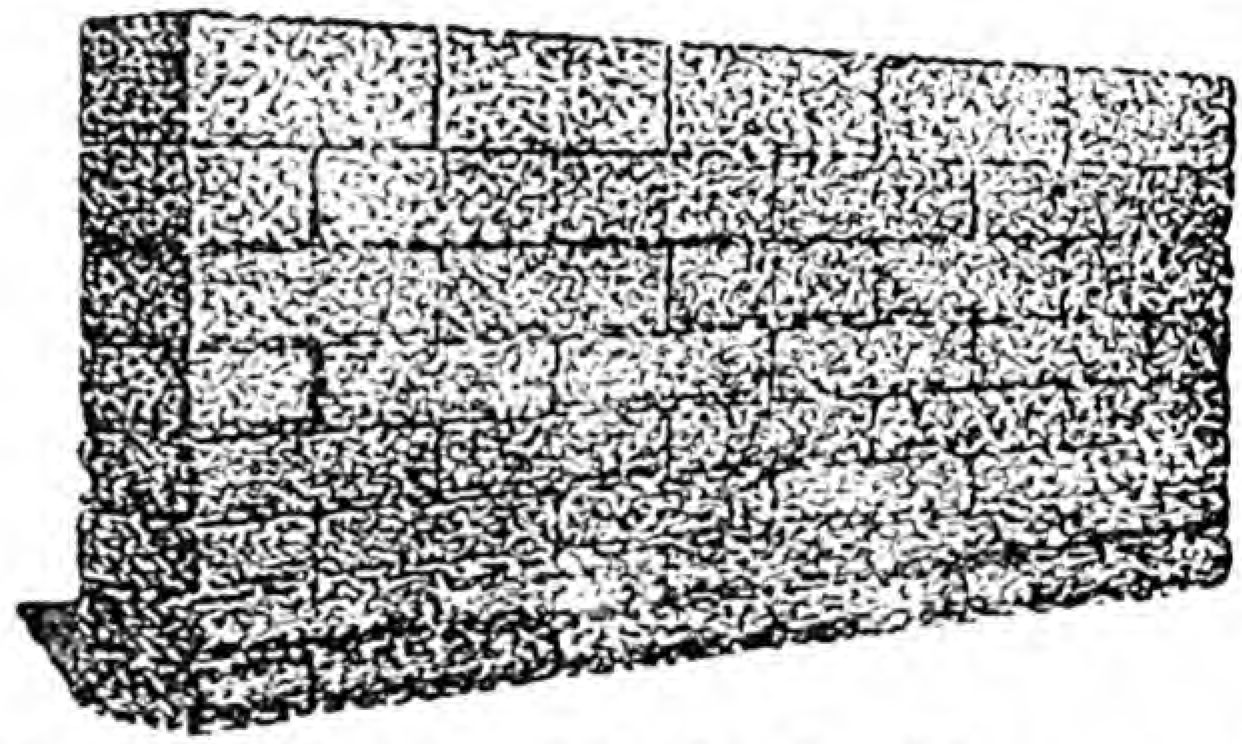


FIG. 79.—*A wall built of rubber sponges shaped like bricks. The bricks at the bottom are squeezed smaller by the weight of those on top.*

a quarter miles—is breathing in the very thin air, which is only just over a third as heavy as it is in low-lying parts of the country.

Proving the Pressure of the Air

We see, then, that the air round us is really under a pressure, and must be pressing hard on us all round. We do not notice the pressure because it is the same everywhere, and our senses do not tell us of pressures like that. The pressure of the air does not break thin bottles and other thin vessels because there is air inside them as well, so that the glass of the bottle, for instance, is just squeezed from both sides in the same way. Even a piece of thin paper is not broken if it is squeezed on both sides, as for instance, if we press on it from both sides with our fingers, as shown in the picture. If, however, in any way we take the air out of the inside of a tin vessel we can easily see that the air really is pressing on the outside, just as if we took away our finger

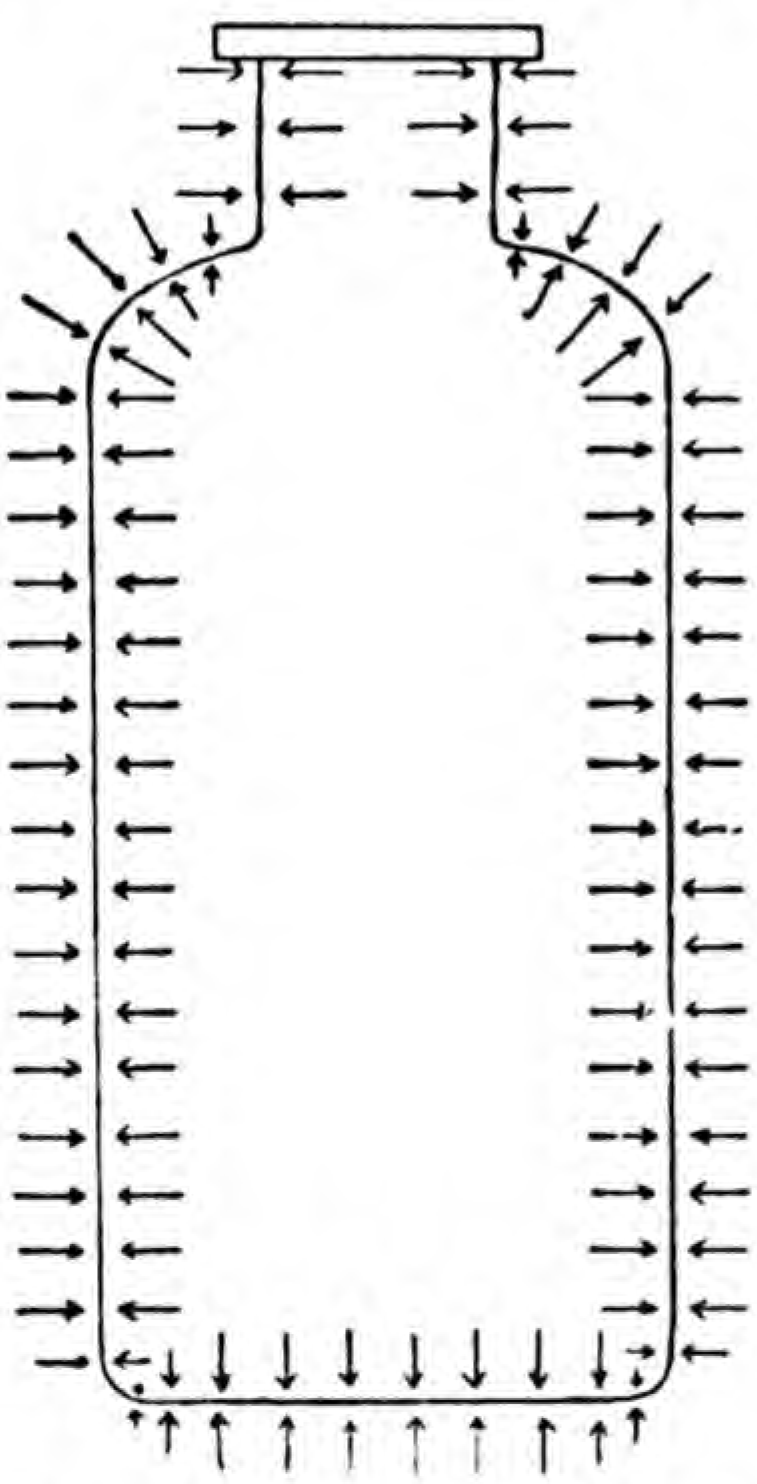


Fig. 80.—*A glass bottle is not broken by the atmospheric pressure, because the pressure inside is the same as that outside.*

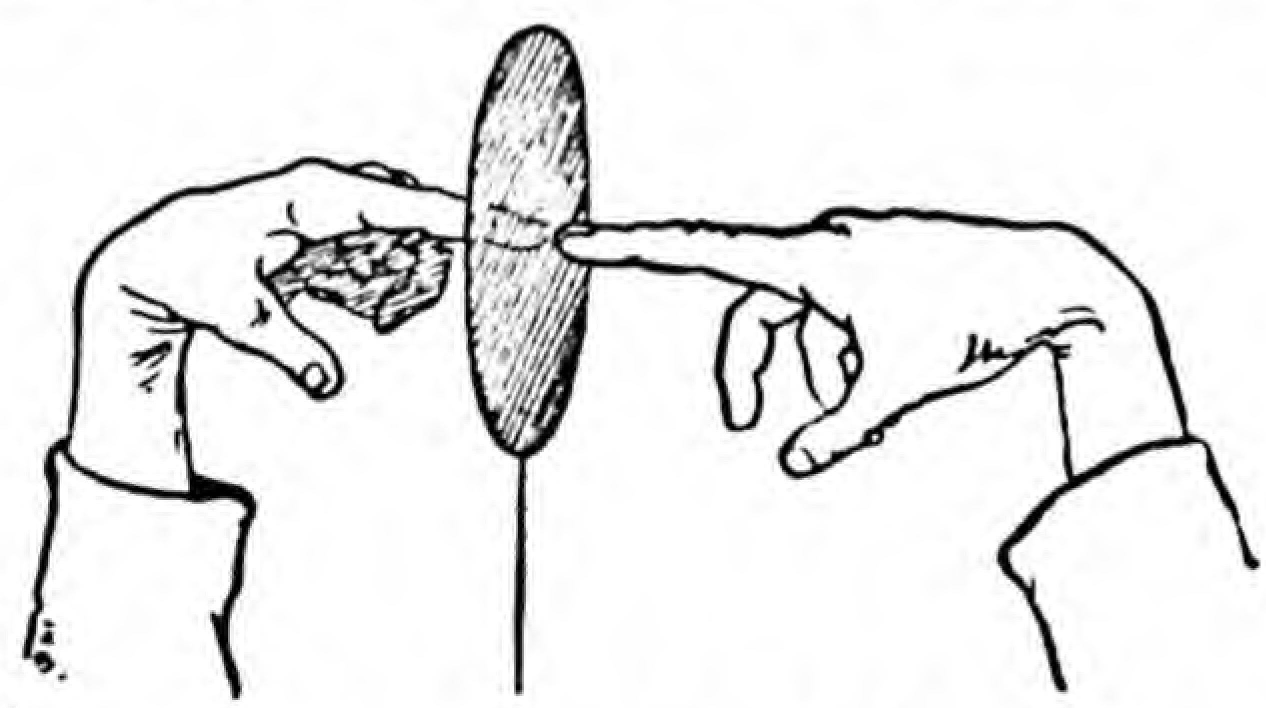


Fig. 81.—*Even a piece of thin paper, mounted on a frame, is not broken if we press on it with two fingers opposite one another.*

from one side only the other finger would at once go through the paper.

A very easy way to do this is to take a thin tin can, of a shape which can be closed by pushing a cork tightly into the neck, and boil a little water in it. After the steam has been coming out for a minute or so we take away the flame, and at once cork the neck tightly, being sure that the cork is a good one and giving it a good twist to fix it well in the neck. If a little cold water is now poured over the tin the sides are suddenly crushed in and it collapses. The reason is that when we corked the flask it was full of steam, and of steam only, for the rush of the steam during the short time that the water was boiling drove out all the air. When the cold water was poured on it the steam condensed to a few drops of water, so that there was, instead of the usual air pressure, hardly any pressure at all inside the tin. It was then unable to stand the pressure of the air from outside, which crushed it in. If we had not poured the cold water on, the steam would in time have condensed in the tin and just the same thing would have happened. The cold water, however, makes the experiment more striking, and leaves little time for air to leak in if the cork does not happen to be quite tight.

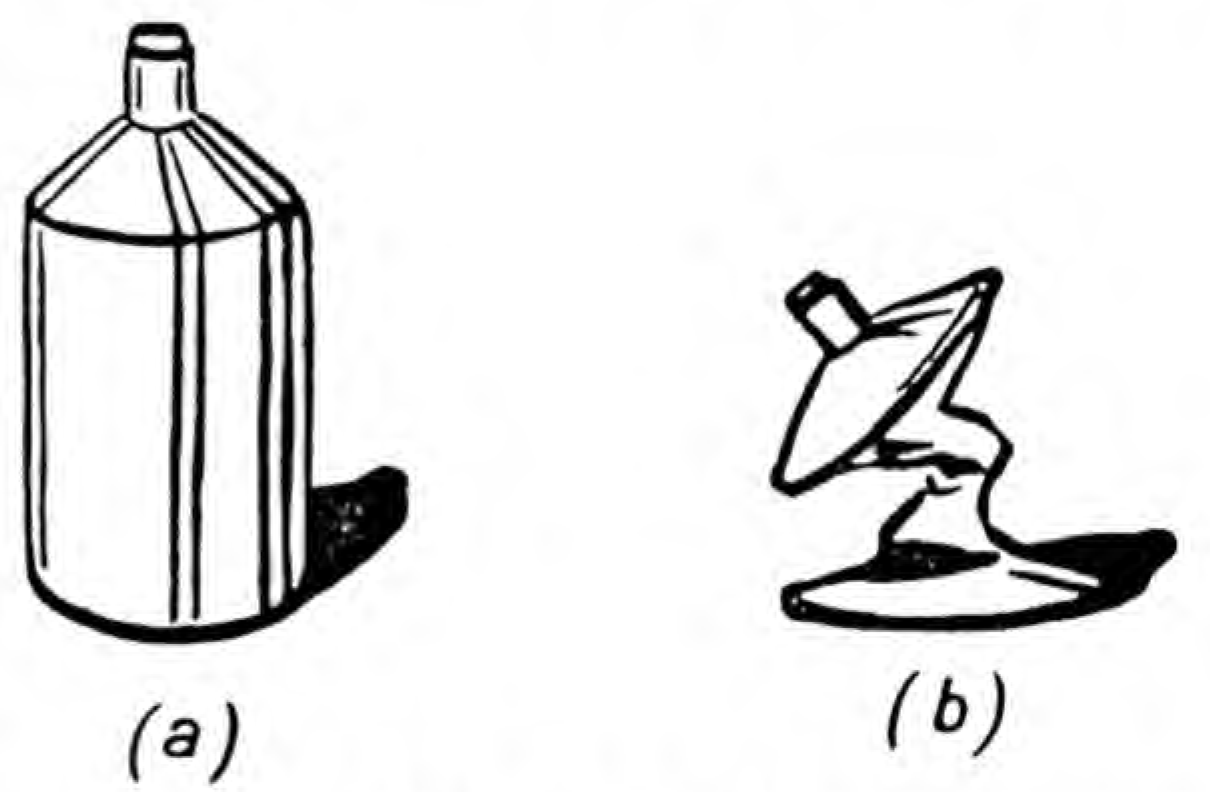


FIG. 82.—*The tin used in the experiment to show the pressure of the atmosphere, (a) before the experiment, and (b) after the steam has condensed inside.*

This experiment shows us quite plainly that the air really is pressing all round, strongly enough to crush in

tins if there is nothing inside them to push against the outside pressure. Inside the large steel chambers which are called the condensers of the turbine engines on steam ships there is hardly any pressure, for the steam is condensed just as it is in the tin of our experiment, and these condensers have therefore to be made very strong, so that they can stand the pressure from outside. This air pressure is sometimes made to do useful work by engineers. For instance, one kind of brake on railway trains depends on air pressure for its action. The picture serves to explain how this happens. The thick black line shows a cylinder

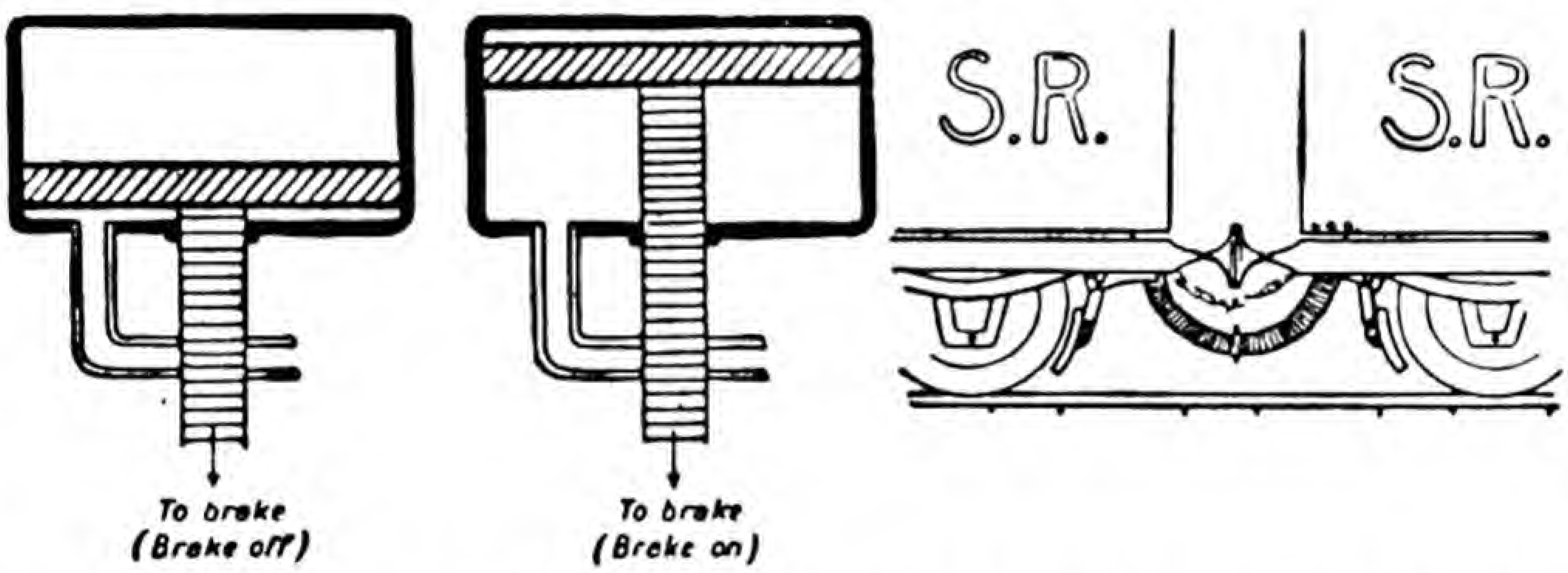


FIG. 83.—*The vacuum brake. The pipe joining the vacuum brakes is seen hanging down between the carriages in the picture on the right.*

cut through, in which a piston, shown by a line shaded slantingly, can move up and down. The piston is fastened to a rod, shown shaded across, which pulls the brake: when the piston is down the brakes are off, and when the piston is up the brakes are on. From the lower side of the piston goes a pipe which is fastened to another pipe, running all along the train, and joined from carriage to carriage by a flexible tube which can easily be noticed hanging in a loop between the carriages, as shown on the right of the picture. On the locomotive is an arrangement which pumps out the air on *both* sides of the piston, so that noth-

ing at all is pressing either above or below, and it lies by its own weight in the position shown on the left in Fig. 83. The arrangement by which the air is pumped out of the top half is not shown in the picture. If now the coupling joining the two carriages should break the tube hanging down between them would be torn apart, the air would rush into the pipe and into the lower half of the cylinder, push the piston up, and so apply the brakes. In this way the engineer is sure that if anything happens which opens the long pipe anywhere the brakes at once go on of themselves. It is

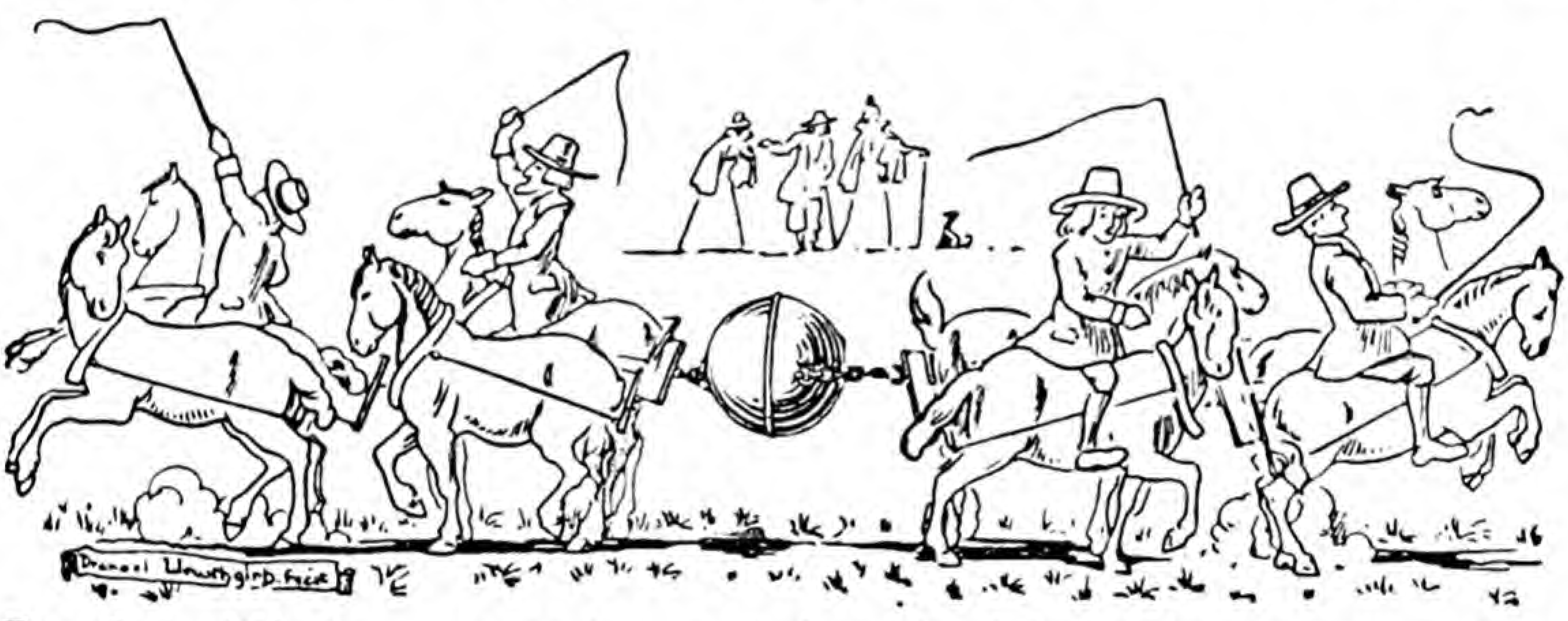


FIG. 84.—*The famous experiment tried at Magdeburg. The two hemispheres are held together so firmly by the pressure of the atmosphere that the horses cannot pull them apart.*

the pressure of the atmosphere that actually pushes them against the wheels, and stops the train.

The first man to make an air pump was Guericke, who died in 1686. He invented a very striking way of showing the pressure of the atmosphere. He had two large copper hemispheres made, which fitted together very neatly, with a ring of leather soaked in wax between them, to make an air-tight join. One of them was made with a short tube through which the air could be pumped out, and this tube was furnished with a tap which could be shut tight when

the sphere was empty. The pressure of the atmosphere on the outside then held the hemispheres together, for there was no pressure from inside to act against it. Guericke then harnessed teams of horses to the two halves, and showed that even four horses a side could not pull them apart. The picture is copied from his book, published in 1672. As the experiment was first made at Magdeburg, in Germany, where Guericke lived, it is often called "the experiment of the Magdeburg hemispheres."

How the Air Pressure holds up Liquids

We only notice the effect of the pressure of the air when it acts on one side of a thing, while on the other side there is no pressure, or only a small pressure. Put a tumbler in a basin of water, so that it fills, and then turn it upside down, still covered by the water. Now lift it up, still bottom upwards, until the lower edge is only just below the surface of the water. The tumbler stays full, because the air pressing on the surface of the water in the basin acts so as to keep the water from running out of the tumbler. There is no air pressure on the top of the water in the tumbler because the glass keeps it off, so that the only thing which tries to make the water run out is the weight of the water, and the air pressure is much more than sufficient to balance that.

Now take a long glass tube, cork one end and fill it with water. Place a finger tightly over the open end, and turn the tube upside down, put the open end in the basin of water and take away the finger. The tube stays full of water, as before, for the same reason. We can easily show that this is only because there is no air pressing on the top of the water column that it stays in the tube, for if we loosen the cork a little air gradually gets in and presses

on the water, so that it runs out of the tube into the basin, and the tube is left empty.

If, after a little air has leaked in, we push the cork firmly in again, the water stops running out of the tube, and we have a column of water standing in the tube, with some air above it. This air, however, is stretched to take up more

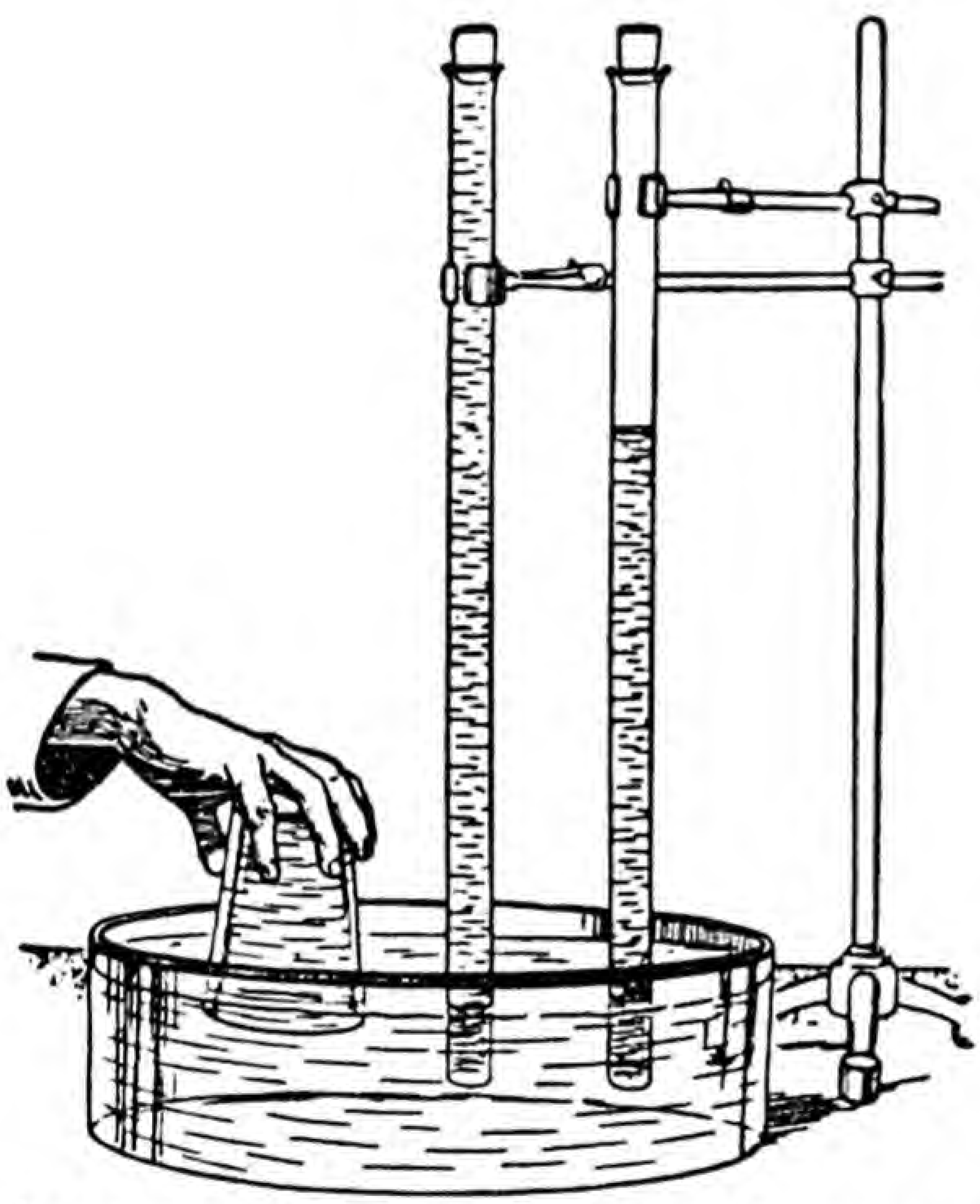


FIG. 85.—*Showing that the air pressure can hold up liquids.*

FIG. 86.—*The pipette.*

space than it would if there were no column of water below it, and therefore it is not pressing as strongly as the atmosphere is. The atmosphere can hold up the short column of water shown in Fig. 85, and also balance the pressure of the air above the water. The difference between the force with which the atmosphere acts, and the force with which the little air on the top of the water acts,

is just sufficient to hold up a column of water of the height which happens. If we let in a little more air the pressure above the column of water gets bigger and the water falls.

There is an instrument called a pipette used by chemists to measure out small quantities of liquids or carry them from one vessel to another. It is a tube which is widened out in the middle into a long bulb, as shown in Fig. 86. The lower end narrows to a small hole, the upper end is cut square. There is a mark at M; when the tube is full from the lower end to this mark it holds a definite quantity of liquid, which is marked on the pipette, say 100 cubic centimetres. To use the pipette, the chemist puts the small end into a liquid, and sucks until the liquid rises above the mark M. He then quickly closes the upper end with a finger, which prevents the liquid running out again, and then, by raising his finger a little, allows a little of the liquid to escape until the level just stands at M. He then keeps his finger firmly on the end, and carries the pipette to his other vessel; when he takes off his finger the liquid runs out. It is the pressure of the atmosphere that keeps the liquid in for him as long as he keeps his finger over the top. The lower end must be made small, so that the skin effect at the surface of the liquid, about which we talked on page 18, will prevent the air coming up between liquid and tube on one side. If you try the same thing with a wide tube you will see a bubble run up one side. More air will get to the top and the liquid will run out, even though you keep your finger on the top of the tube.

The Barometer

The air pressure, as we have seen, will hold up a column of water 2 or 3 feet high, the weight of the water

not being sufficient to make it run down against the pressure on the surface of the water all round. If, however, we try longer and longer tubes, clearly a stage will be reached when the column of water is so heavy that the pressure cannot hold it up, and it will run from the closed end of the tube, not right down, but to a position where the weight of the column is just balanced against the pressure of the atmosphere. To show this we should want a very long glass tube, for the air pressure can actually hold up a column of water about 34 feet long. Of

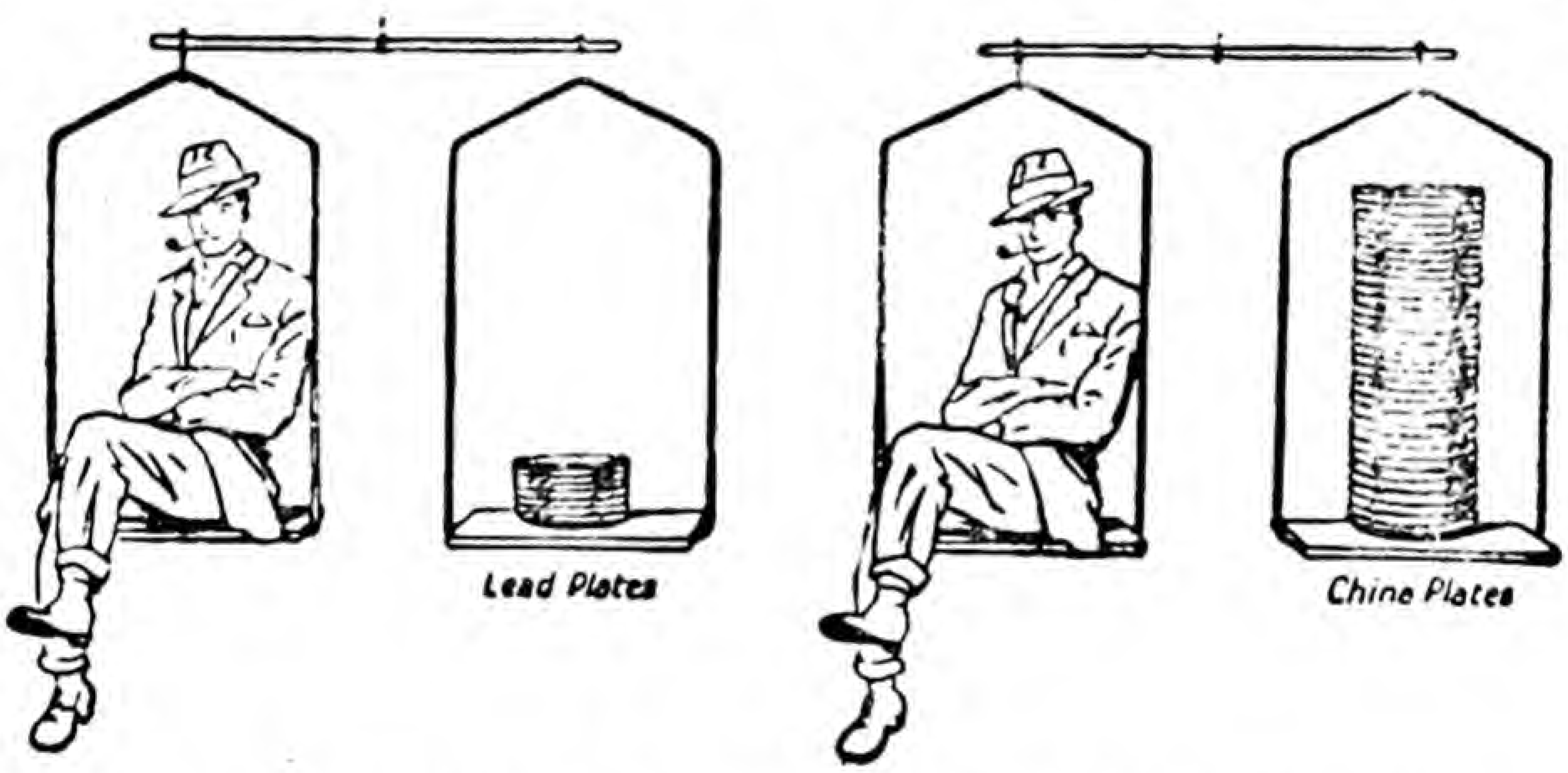


FIG. 87.—*A man balanced by a short pile of lead plates (left) or a tall pile of china plates (right).*

course, if we use a liquid that is heavier than water the column which the atmospheric pressure can hold up will be shorter. If the weight of a man pressing down on a scale can hold up a pile of china plates which is 3 feet high on the other pan, he will only be able to support a pile of similar plates made of lead which is 7 inches high. because lead is so much heavier than china. We nave already spoken of the liquid mercury which is so heavy that a flatiron will float on it. It is actually about thirteen and a half times as heavy as water, so that it will require

a column of mercury only $\frac{2}{27}$ as high as that of water to balance the atmospheric pressure—that is, $\frac{2}{27}$ of 34 feet. This is $\frac{2}{27} \times 34 \times 12$ inches $= 30\frac{2}{9}$ inches. We shall not be far wrong if we say 30 inches; in any case, the column of water is not exactly 34 feet long.

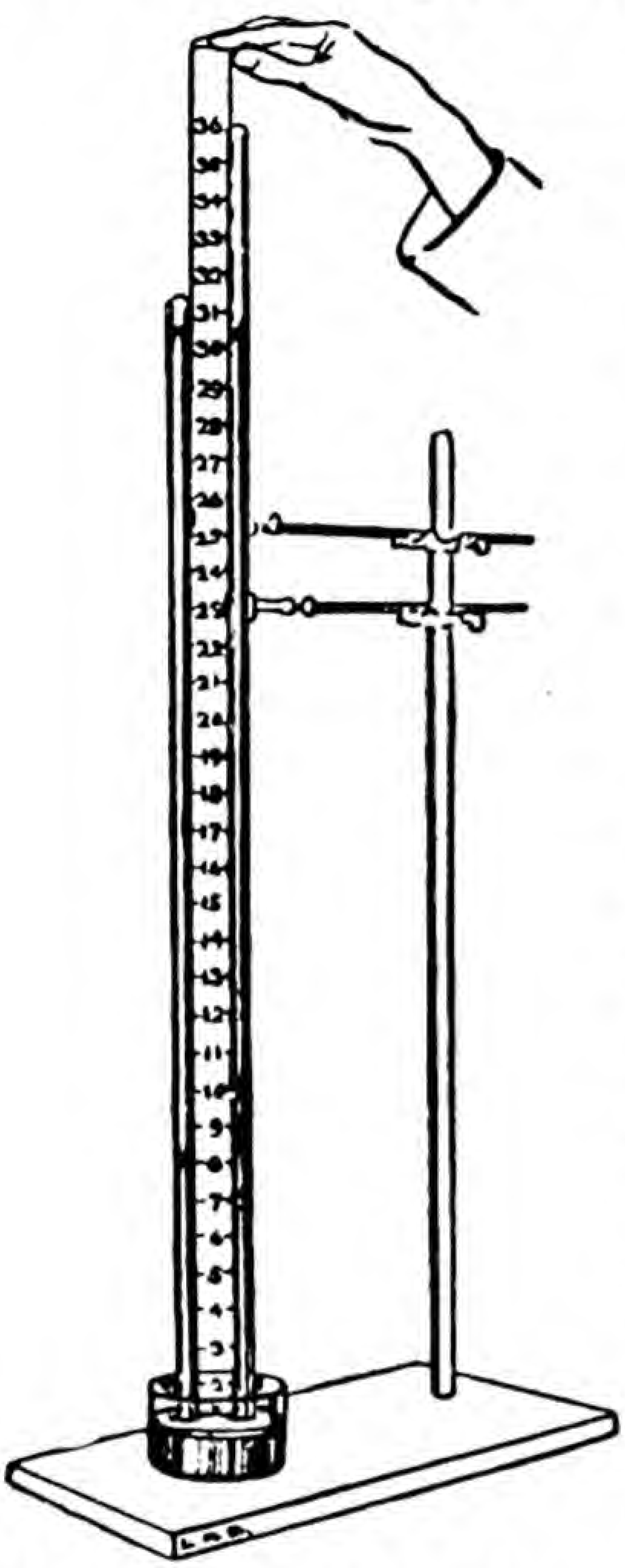


FIG. 88.—*The mercury stands at the same height in both tubes, although one is longer than the other. In both tubes there is an empty space above the mercury.*

We now take two glass tubes, sealed up at one end, one about 3 feet long, and the other some 6 inches longer, and, if it is possible, dry them well in front of a fire or some other source of heat. We fill them both carefully quite full of mercury, and then take one, place our finger tightly over the end, so that no air is shut in, turn the tube over, place the end under the mercury in a small dish, and remove the finger. We do the same with the other tube, and fix them side by side with a clamp. We see that the mercury does not fill the whole tube, but stands at exactly the same level in both tubes, although one is longer than the other, and on measuring we find that the length of the mercury column from the surface of the mercury in the dish is about 30 inches.

Above the mercury in the tube is a space which contains nothing, for it was first of all full of mercury, and when the mercury ran out of it nothing else ran in, in particular no air. It clearly makes no difference

how big the space is if it is completely empty. There is nothing pressing on top of the mercury, and only its own weight is trying to pull it down. On the surface of the mercury in the dish the atmosphere is pressing. The height of the mercury column exactly measures the strength of the pressure of the atmosphere. A mercury column of this kind, with some kind of a divided strip to read off the height, is called a *barometer*, which is a word made from two Greek words meaning *pressure* and *measurer*.

Everybody knows that the barometer is used as a help in forecasting the weather. The pressure of the air is not always exactly the same, and by the barometer we can measure how it changes. On the average the height of the barometer in England is just under 30 inches, but occasionally it sinks as low as $27\frac{1}{2}$ inches, and rises as high as 31 inches. Actually the highest pressure ever recorded in England is $31\frac{1}{10}$ inches, while the lowest is $27\frac{1}{3}$ inches. When the pressure is falling bad weather may be expected, while a rising barometer usually means fine weather. Seamen in particular rely greatly on the falling barometer to warn them of approaching storms: before a violent storm the height has been known to drop an inch in half an hour, but such a rapid fall is very unusual.

Another purpose for which the barometer can be used is to measure heights, on mountains or in aeroplanes. The higher we go the less atmosphere there is above us, and the lower the pressure is, as has been already explained. The table on p. 122 shows the reading of the barometer at different heights on a day when the reading at the surface was 30 inches.

The heights which belong to any reading of the barometer between the whole number of inches given can be worked

out, so that a man need only carry a barometer with him on a mountain and he can tell how far up he has climbed. A good barometer will show easily a difference of reading at the bottom and at the top of a building.

Height (*Feet*).	*Barometer* (*Inches*).
0	30
950	29
1,900	28
2,900	27
3,950	26
5,000	25
6,050	24
7,200	23
8,400	22
9,600	21

The Aneroid Barometer

The barometer used in aeroplanes and on mountains is usually not a mercury barometer, but one made in quite a different way. We have seen that the atmosphere can smash in a tin when the air has all been removed from inside. Now suppose that instead of a tin we had a springy hollow box of steel, strong enough not to be crushed in, but springy enough for the top and bottom to be a little squeezed together by the pressure of the atmosphere. If the pressure increased, the box would be a little more squeezed; if the pressure fell, a little less squeezed; and if we added to our box some way of measuring the amount of squeezing, we should have a barometer.

Barometers made on this idea are called *aneroid* barometers: the word aneroid comes from Greek words which mean "containing no liquid." The box is flat and has the

top and bottom corrugated, which makes it strong but springy. The air is pumped out and the box sealed air-tight. To prevent the top and bottom being quite pushed together, a steel spring is provided which holds the top

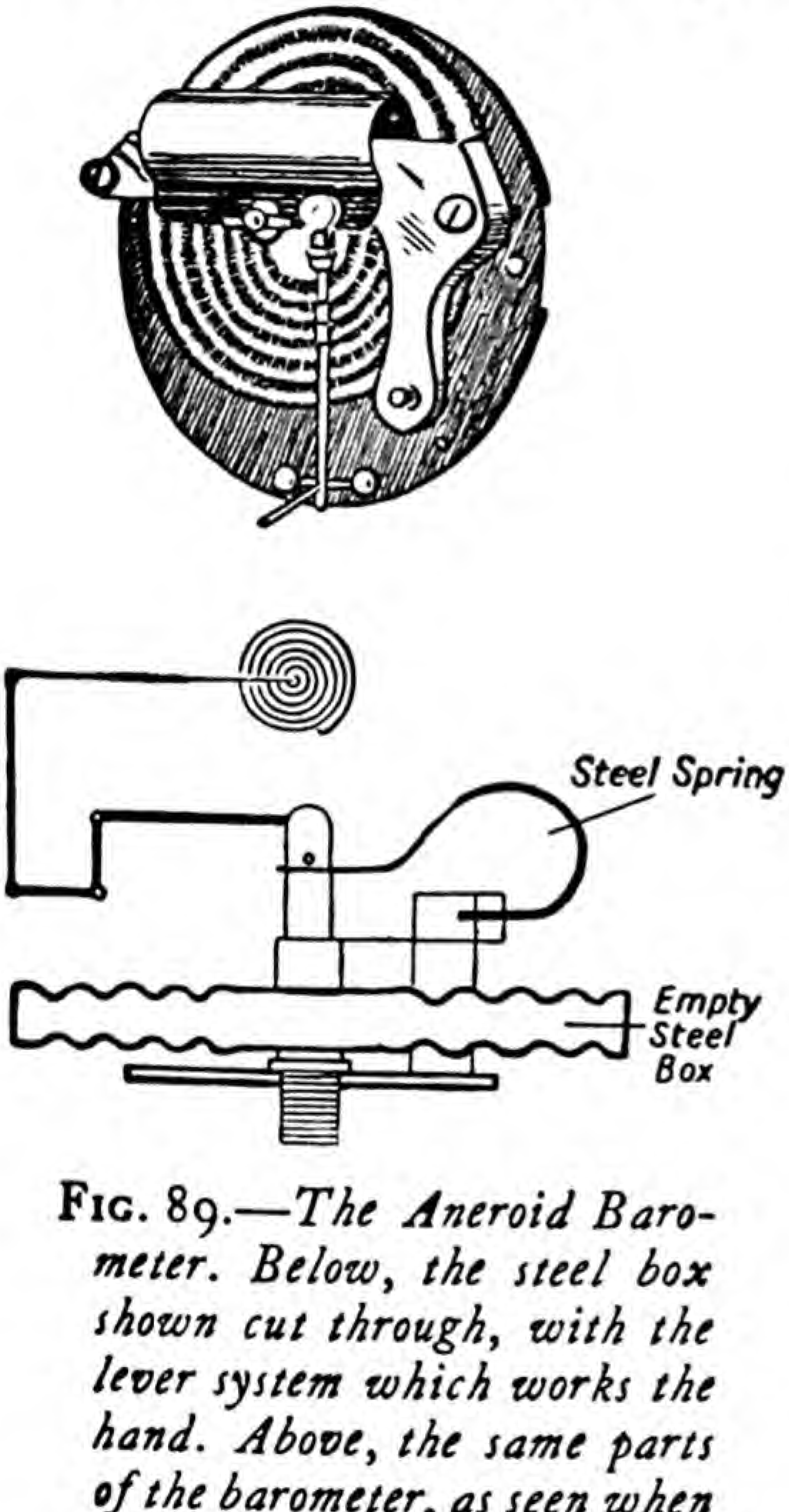


Fig. 89.—*The Aneroid Barometer. Below, the steel box shown cut through, with the lever system which works the hand. Above, the same parts of the barometer, as seen when the front is taken off the instrument.*

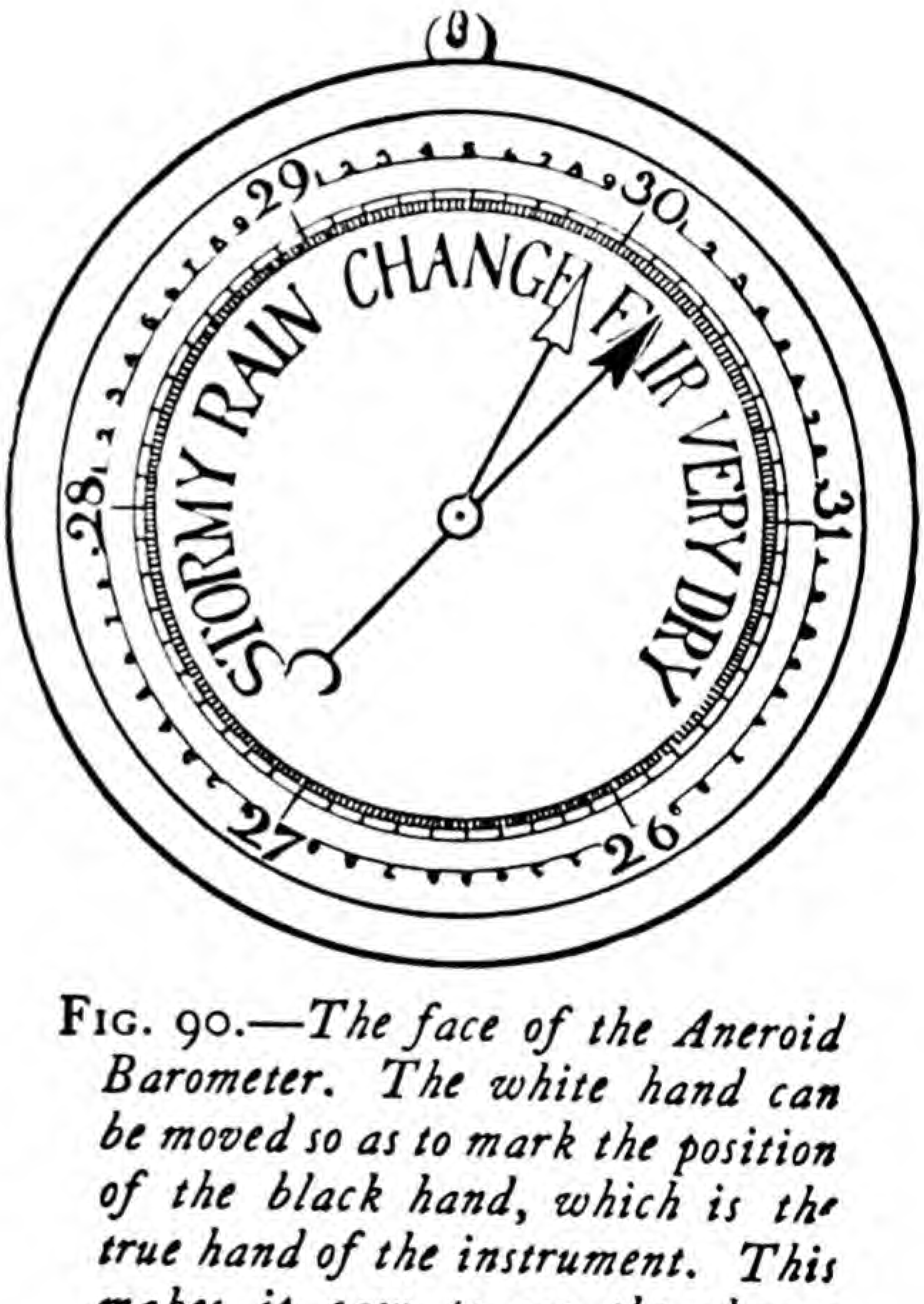


Fig. 90.—*The face of the Aneroid Barometer. The white hand can be moved so as to mark the position of the black hand, which is the true hand of the instrument. This makes it easy to see the change since the white hand was last set.*

up, as shown. As the pressure of the atmosphere alters the top of the box moves up or down a little, and this movement is, by a series of little levers, made to turn a hand on the face of the instrument, shown in Fig. 90. A barometer of this kind can be carried in the pocket, or mounted

on the instrument board of an aeroplane. When a barometer of this kind is marked on the face so as to give heights it is called an *altimeter* or height measurer. In some very hilly places, like Kenya colony, people often have altimeters fitted to the instrument boards of their motor cars, to record the height to which they climb.

A barometer of this kind can be made to write down the pressure in ink on a chart. To make the movement bigger there are usually several boxes, often seven, fixed one above the other. A movement of the top of the pile of boxes works a long arm with a little pen at the end, which draws with ink on a piece of paper wrapped round a clock-work drum. We know by marks printed on it which part of the paper was opposite the pen at a certain hour, and by the ink mark at that place we can tell what the height of the barometer was. An instrument of this kind is called a self-registering barometer.

Warm and Cold Air

We must now consider the effect of making air hot. When air is warmed it expands, which means that the same amount of air takes up more room than it does when it is cold, unless it is prevented by pressure. Let us take a thin rubber balloon and blow it up with a football pump or a bicycle pump until it is smooth all over. If we now hold it near a fire or warm it in any other way, as, for instance, by holding it in a basin of very hot water, we shall find that the balloon becomes bigger and tighter. We can see this increase in size, but to make sure it is better to measure round it with a piece of thread, first of all when it is cold, and afterwards when it has become hot. Of course if the air is shut up in a metal ball instead of a balloon the metal would not stretch when the air was heated. In this

case the pressure of the air, kept in by the unstretchable skin, would become greater, just as it would if we had pumped some more air in. The air, when heated, always expands if it can, but if it cannot it presses more strongly against the walls that keep it in. If a motor tyre is pumped up in a cool place, such as a garage, and the car is then taken into the sun, which heats the tyres, and also driven over a rough road, which heats them still further, the pressure in the tyres goes up.

Since air, if not shut in, takes up more room when it is heated, hot air must be lighter than cold air, and will float up through the cold air like a cork floating up through water. For this reason the hottest air in a room is always up near the ceiling. In a theatre the hottest air rises to the top of the building, and it is much warmer in the gallery than in the stalls. The air which we breathe goes into our noses cool, and comes out of our lungs very much warmer, so that the breathed air goes to the top of the room. For these reasons, when it is wished to let the bad air out of a room and the fresh air in, which is called *ventilating* a room, there must be an opening high up to let the bad air out, and an opening lower down to let the good air in. A window should therefore always be opened at the top, especially in a bedroom. The used air can then stream out as shown in Fig. 91, and, even if the window is not open at the bottom, fresh air can easily get in between the two halves of the window. If a good airing is wanted it is best to open the window a little at the bottom too. If, however, the window is open at the bottom alone the hottest and worst air is trapped near the ceiling and for some way down, and only gets changed very slowly.

The draught up a chimney is caused by the hot air rising quickly: the hotter the fire the bigger the draught,

and the more the fire roars as the air rushes in to take the place of that passing up the chimney. A fire in an open grate helps to ventilate a room, for the hot air rising up the chimney takes with it some of the used air in the room, and fresh air has to get in under the door, even if the window is not open, to take its place.

The rising of warm air can also explain many things about the weather.

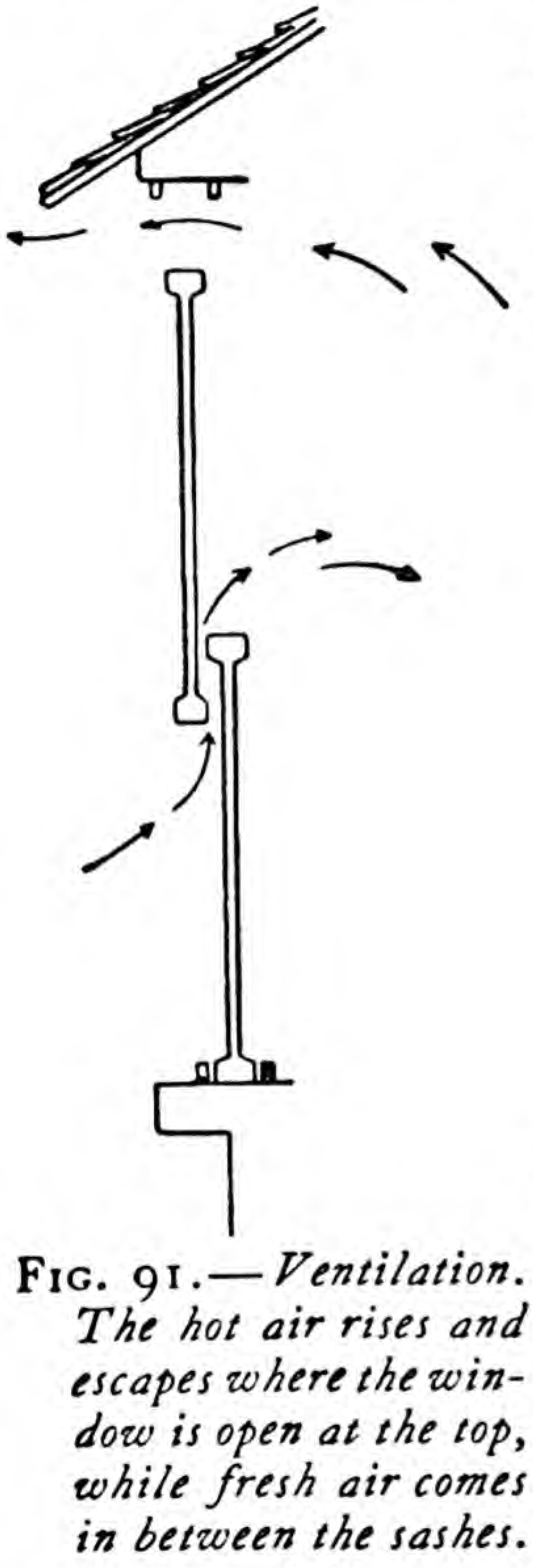


FIG. 91.—*Ventilation. The hot air rises and escapes where the window is open at the top, while fresh air comes in between the sashes.*

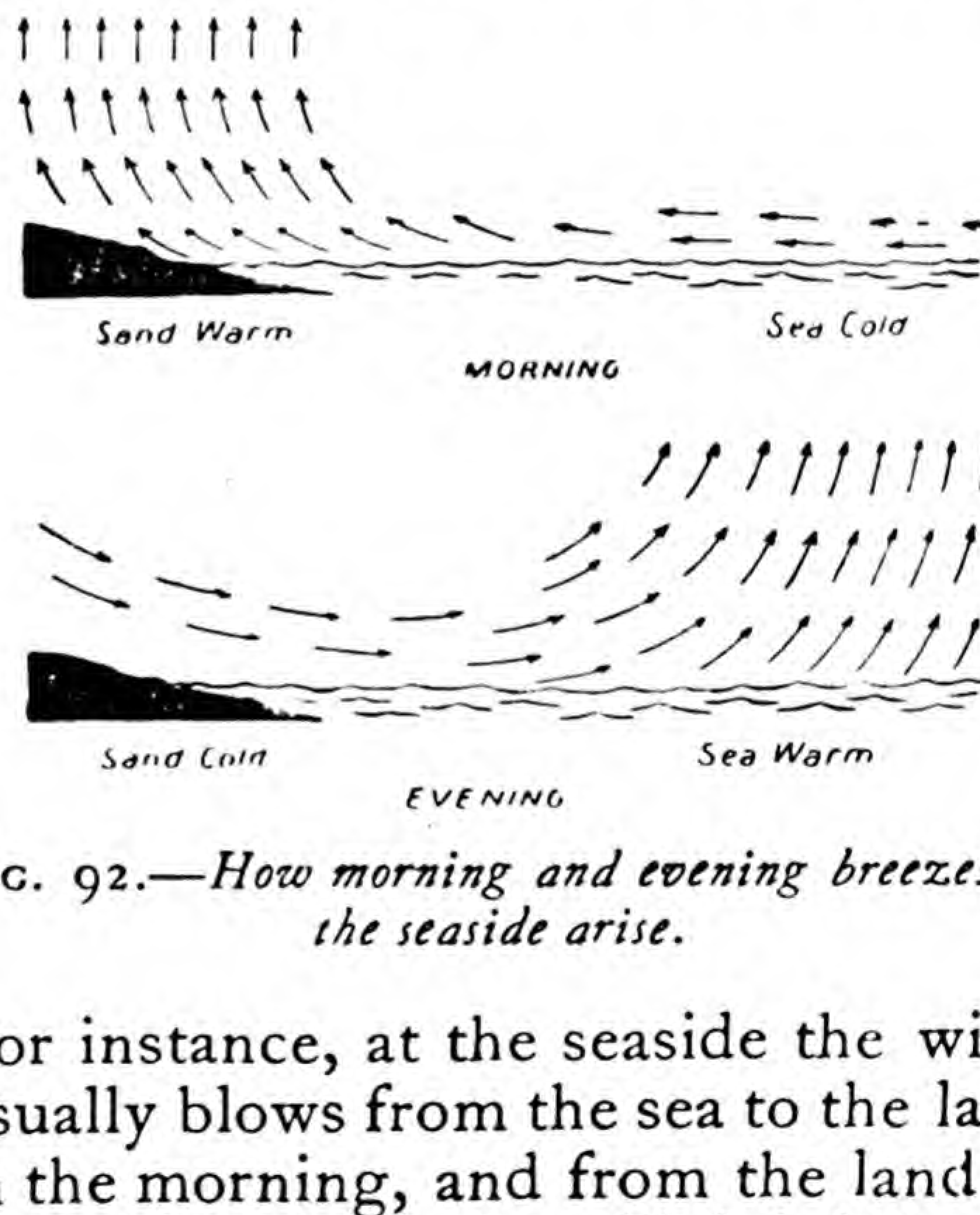


FIG. 92.—*How morning and evening breezes at the seaside arise.*

For instance, at the seaside the wind usually blows from the sea to the land in the morning, and from the land to the sea in the evening. This is because it takes more heat to warm the water than to warm earth, so that in the morning, when sunlight falls on land and sea, the land gets hot first. The air on the warm land becomes warm itself and rises, and the air comes in from the sea to take its place. As the day goes on the sea

gets warm too. In the evening when the sun has set the earth cools more quickly than the sea, just as it heats more quickly in the morning, so that the sea is now the warmer of the two. The air over the sea rises more quickly, and the air from the land moves out to take its place. You can easily test this when you are at the seaside: on a sunny day the beach is warmer than the sea in the morning, but the sea warmer than the beach in the evening.

The first balloons made took great advantage of the fact that hot air rises. They were made of silk, oiled or varnished, and were in the form of a bag turned upside down, with the neck open. They were filled with hot air from a fire or a brazier, which was hung under the opening of the balloon. Such balloons were called fire balloons, and men first went up in them in the year 1783. They were always rather dangerous, of course, because of the chance of the balloon itself catching fire, but many ascents were made, and a large fire balloon was sent up in London at late as 1864. Toy balloons can be made consisting of a large paper envelope, with a wide opening below, in the centre of which a small sponge is held by a wire. The sponge is dipped in methylated spirit

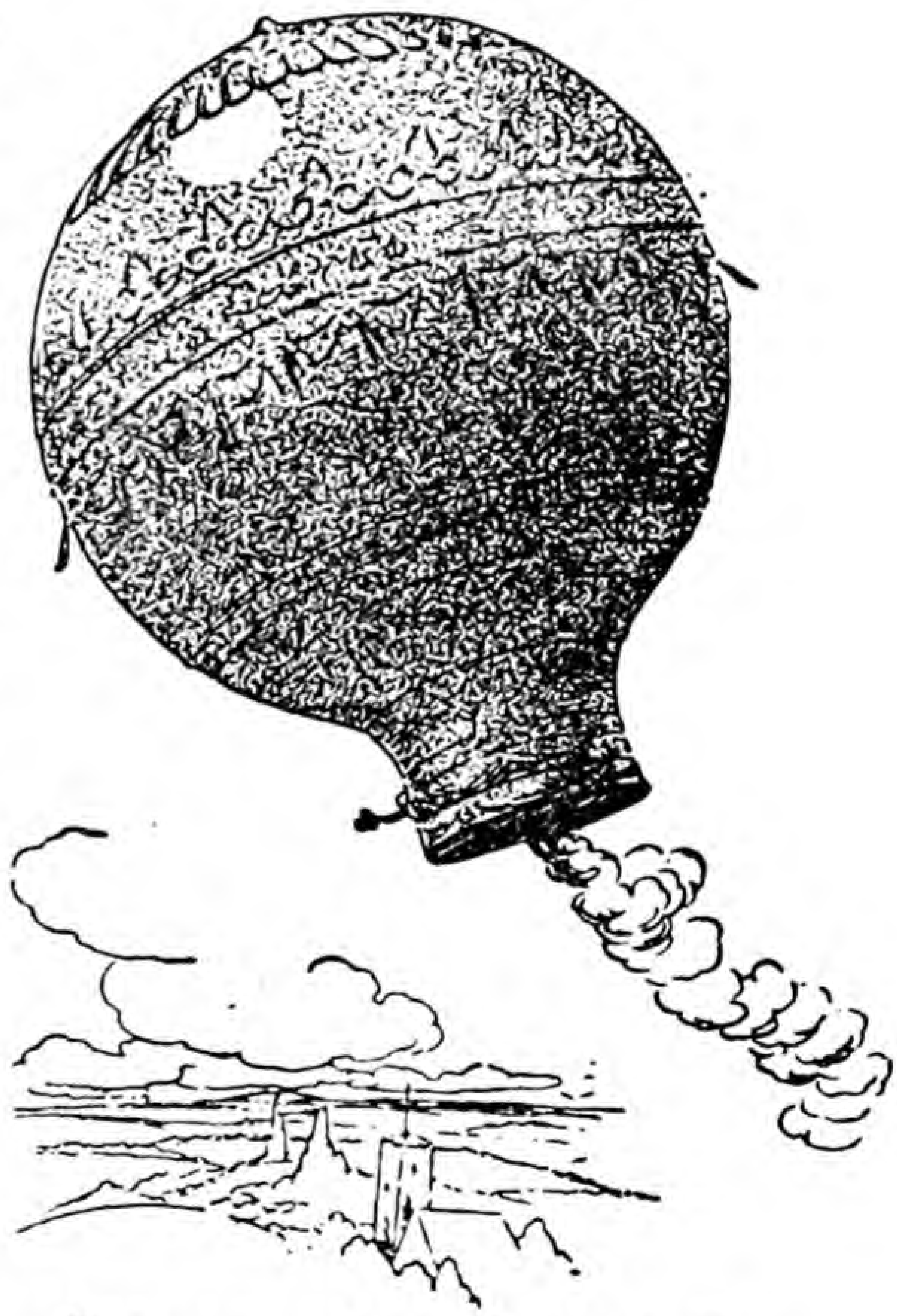


FIG. 93.—*An early fire balloon.*

and lighted, but care must be taken not to set the balloon itself on fire.

The Water in the Atmosphere

If a jug of really cold water is brought into the room on a hot day the outside of the jug will soon become covered with a kind of mist, which will a little later form large drops of water. In the same way, pipes which carry cold water through a warm room are always covered with drops. These drops are not water which has leaked through the jug or the pipe, nor are they, as people thought at one time, air which has turned itself into water, for, as we now know, air cannot turn into water. They are formed from water which is held in the warm air in the form of invisible vapour, like the true steam that is close to the spout of the kettle; some of it can no longer be held in this invisible form when the air is cooled.

To show the water drops forming from the air we put some water, which has been standing in a jug in the room, into a brightly polished copper pot, and wait a few minutes to show that no water is leaking through. We then put into the water some crystals of sodium hyposulphite, which photographers call simply "hypo," and stir. When this substance is dissolved in water it makes the water very cold, as can be shown with a thermometer, or simply by putting a finger into the water after the experiment is over. In a short time a faint mist, which is really tiny drops of water, appears on the bright copper, and after a few minutes drops of water will form and run down the sides. Now let us take another pot, exactly like the other one, and put it into a glass vessel which is just a little larger, joining the two together at the top with a ring of rubber. There will be a very small quantity of air between the

copper and the glass, and no fresh air can get in. If, now, we do the experiment again, filling the copper pot with water and putting in hypo, the copper surface will remain bright, with no drops on it. The amount of air which can touch the pot is so small that the water which it contains is not sufficient to form one drop. This shows us that the water must come from the air.

If it seems strange that there is water in the air which can be made to come out of it, let us look at things the other way round. Suppose we put a shallow saucer of water in a warm room on a dry day, and leave it: we know that the water will disappear, dry up, or evaporate, as it is called. Where has the water gone? Clearly it must have gone into the air in the form of invisible vapour: there is nowhere else for it to go. In the same way, if we put a wet cloth near a fire it becomes dry: the water in it becomes vapour, which cannot be seen. If water can thus disappear into the air it is not surprising that it can come out of the air again. It has never actually vanished, but merely changed from the liquid to the vapour form. It is rather like the hero in the fairy story who puts on a cap of invisibility and vanishes, and takes it off and reappears again at will. He is there all the time, but sometimes he is in visible form, and sometimes invisible.

The hotter the air the more invisible water vapour it can hold. On a very wet day, when everything is moist, the air has as much water vapour as it can hold, and a saucer of water will not evaporate, or will only evaporate extremely slowly. If we just stand under a shelter our wet clothes will not dry. But if we go into a hot room, where the air can hold more moisture, they will give up their water. The reason why the water drops form on the cold surface is now clear. The water vapour in the air, at the

temperature of the living-room, may be actually less than the warm air can hold, but at the same time be more than very cold air will hold. The air near the cold surface, therefore, becomes cold, and has to part with some of its water, but cold air, we know, is heavy and sinks, and so fresh air will all the time be coming in contact with the cold surface, and give up some of *its* water, and so on.

Frost and Fog

If we go into a cold storage room, where there are pipes full of cold brine to keep the temperature low, we shall see that these pipes are covered with frost and ice. This is not because water has been spilt on them, but because the water from the air first forms drops on the surface, as we have seen, and then, so cold are the pipes, freezes. This is just the kind of thing that leads to a white frost. There may have been no rain, but if the trees and the surface of the earth suddenly become very cold at night the water comes out of the air on to them, and then freezes into what is called hoar frost. The beautiful ice crystals which form *on the inside* of glass windows, especially bedroom windows, on very cold nights, are formed in the same way. The warmer air of the bedroom becomes very cold just where it touches the window, and gives up most of the moisture, from the breath and so on, which it holds. A thin film of water is so formed on the window, and freezes there into ice crystals.

Sea fogs are generally formed by warm moist air coming into contact with the colder air lying just above the cold water of the sea. As a whole thick layer of air is cooled in this way the moisture which the air cannot hold comes out as little drops, which are held suspended in the air. A fog is nothing but a great mass of tiny drops of water.

We can always make a little fog of our own, on a cold day, by breathing out strongly. The moisture in our breath, invisible on hot days, is mostly changed into little drops when it strikes the cold air.

It is very difficult to understand all about the weather, because so many things are changing at the same time, as, for instance, the temperature and pressure of the air, the speed with which it is moving, and the amount of moisture in it. It is, however, by studying the laws which the air and the moisture in it obey that men have been able to build up a science, called *meteorology*, which deals with the weather, and which is able to give us some idea in advance of what it is going to be like. There is a great office in London, called the Meteorological Office, where reports of the pressure and other conditions of the air in various places are received all day long. The people who work out from these reports the forecasts which we receive need to know a great deal about the way in which moist air behaves, to help them in their task. The most important instrument on which they rely for their forecast is the barometer, about whose construction we have learnt in this chapter.

CHAPTER VI

WATER

Water Everywhere

WATER is one of the most widely spread and important substances known to us. The clouds are nothing but little drops of water, the air contains water in the form of invisible vapour, and, except in arid deserts, the earth, too, contains water. Without water there would be neither animal nor vegetable life. Not only do living things need water to keep them alive, they are themselves largely water. Our blood is mostly water, and our bones and flesh contain water too; in fact, 59 per cent. of a man's weight is made up of water. Fifty-nine per cent. means 59 parts in a hundred, which is only slightly less than three-fifths. Of a ten-stone man, just upon six stone are water. If we consider his muscles only he is even more watery, for they weigh about sixty pounds, of which about forty-seven are water.

Vegetables are still more watery. A potato is about 75 per cent., or three-quarters, water: an apple is 86 per cent. water: a cabbage over 90 per cent. water: while a cucumber is 96 per cent. water, which means that of a cucumber weighing 1 lb. 9 ozs. only one ounce is anything but water. Think how indigestible that ounce must be! Some water-melons are 98 per cent. water. Some forms of animal life, like certain kinds of jelly-fish, are even more watery, containing as they do over 99 per cent. of water. If a jelly-fish is left exposed to the hot sun on

the sand, the water will dry away, and in a short time only a mere film of solid stuff is left. Even of the best milk, as it comes from the cow, nearly seven-eighths is water. Every kind of ordinary food has water in it.

A great many solid substances that look perfectly dry contain water, especially crystals. A piece of crystalline washing soda or of copper sulphate (the bright blue crystals sometimes called "blue vitriol") is perfectly dry and hard to the touch, but contains water somehow built into the crystal. Crystalline washing soda is roughly 63 per cent. water, blue copper sulphate about 36 per cent. water. We can drive the water off by putting a piece of the substance in a test tube and strongly heating it. The washing soda goes a chalky colour, and loses its transparency and its clean crystalline form, while the copper sulphate goes crumbly and *white*, in the places that are hottest, instead of *blue*. The cool walls of the tube quickly become covered with drops of water, which has been driven off from the crystal in the form of steam, and has condensed again to water. The end of the tube should be held pointing somewhat down, as in the picture, so that these drops do not run down on to the hot glass and crack it. When a few drops of water are poured on to the waterless white copper sulphate it turns blue again. This water contained by crystals as part of their structure is called "water of crystallisation."

FIG. 94.—*Blue copper sulphate heated in a test tube, with the water from it condensing on the walls.*

Different Kinds of Water

In everyday life we speak as if there were many kinds of water. There is fresh water and sea water, hard water and soft water, spring water and boiled water, tap water and distilled water, for instance. These different kinds of water can be distinguished from one another by easy tests. Tasting will tell us which is sea water, for it is very salty, and which is spring water, for it tastes very fresh and brisk. By the aid of a little piece of soap we can tell hard water, such as comes from the tap in most parts of the country, from soft water, such as rain water, for with the soft water we can make a lather very easily, while with the hard water we get a kind of curd formed at first, and can only obtain a lather by adding still more soap after that. When the water is hard a thick rim of curdy substance always forms round the edge of a bath at the surface of the water if soap is used. Boiled water tastes very flat. If a little of a substance called silver nitrate is added to any tap water the water becomes slightly milky, but if it is added to distilled water the water remains clear. The different kinds of water really are different, then.

That is what we should say at first. However, of all the different kinds of water just mentioned only one is pure water and nothing else: all the others are water with something added to it. Distilled water is the pure one. It is prepared by boiling water in a vessel such as A (Fig. 95) and making the steam which comes from it pass on to a cold surface so that it turns back to water. The cold surface in this case is a tube, twisted into a long coil as is shown at B, which is kept cool by water from a tap running over the outside. Such an arrangement, in which a liquid is heated and the vapour which comes from

it turned back to liquid at a cold surface, is called a *still*, which is why the water is called distilled. The distilled water is run off at C. Such a still is also used in the preparation of alcohol for methylated spirit, and of whisky.

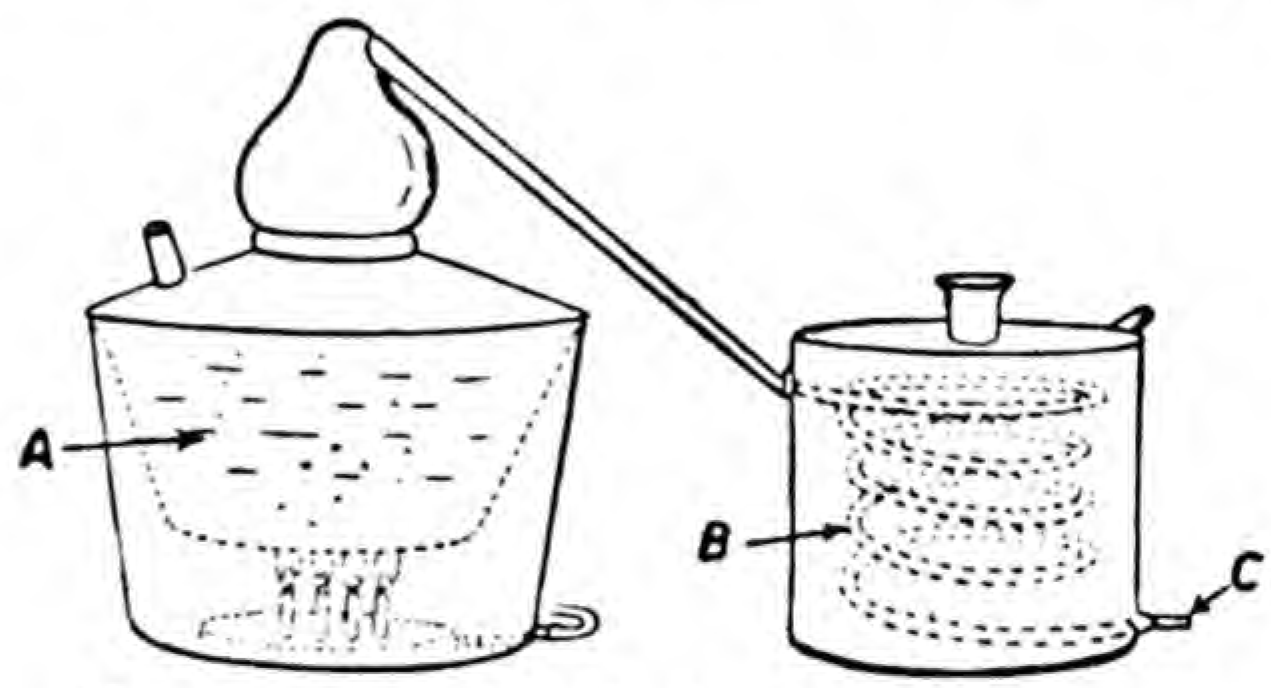


FIG. 95.—*A still for preparing pure water.*

Why is distilled water pure? Because, even if the water which we put into the vessel A is impure, and has things dissolved in it, the steam which comes off is just water, the dissolved things being left behind. When we let the steam turn back to water, that water has no impurities in it.

Sea water is pure water with salts—ordinary cooking salt, with other substances something like it in smaller amounts—dissolved in it. There are about $3\frac{1}{2}$ lbs. of salts in 100 lbs of sea water, but the amount varies from sea to sea and from ocean to ocean in different parts of the world. If we put some sea water in a porcelain dish, of the special kind used in chemical laboratories, which will stand a flame, and gently heat it, all the water will in time pass away as steam, and the salts will be left behind in the dish and may be safely tasted.

Spring water is pure water with not only certain mineral substances dissolved in it, but also gases, chiefly that gas which we have often mentioned, called carbon dioxide. This gives it that crisp, fresh taste. Ordinary soda-water is water with carbon dioxide added artificially.[1]

[1] When it was first made, some sodium bicarbonate was added to the water, which gave it the name soda-water. Today it is simply water aerated with carbon dioxide under pressure.

Even ordinary tap water always contains some dissolved air and carbon dioxide. If it is heated the dissolved gas comes out of the water: to get rid of all of it the water must be boiled. Before water has really come to the boil bubbles will be seen coming up through the water: these are bubbles of the dissolved air, unlike the bubbles when it is boiling vigorously, which are of steam. Water which has been boiled and allowed to cool has, therefore, no dissolved air or other gases in it, and tastes flat.

Ordinary tap water always contains solid substances dissolved in it, as can be proved by boiling some of it quite away in a porcelain dish. It will be found that a deposit of a whitish or brownish substance will be left. This solid deposit consists of various chemicals, the chief of which are what chemists call salts of calcium and magnesium. It is these substances which combine with soap to form the curdy substance which makes the ring round the bath. The soap is used up—wasted, from our point of view—to form this unpleasant curd, and until enough soap has been added to turn all the stuff dissolved in the water into this mere nuisance no lather can be formed. Water with such dissolved substances in it is called "hard." When we put hard water into a kettle, and boil it, some of the dissolved solids come out and settle on the sides of the kettle, and this is what the housewives call "fur." Sometimes they put a piece of loofah or brush in the kettle, and then much of the fur settles on that instead of on the kettle, and can be removed. This fur, which engineers call boiler scale, can be very troublesome in boilers, for it collects in the tubes and prevents the heat of the furnace getting to the water so readily. There are many compounds sold to prevent boiler scale, most of which are chemicals leading to a scale that is

lighter and more easily removed than that formed from ordinary hard water. If nothing but really pure water were ever put into a boiler there would, of course, never be any scale, and the steam engineer's life would be easier.

There is, then, really only one kind of water, but various substances may be dissolved in it, which leads to the general impression that there are several kinds.

Salt Water

The sea is water with various chemicals, mainly common salt, but also substances called magnesium chloride, magnesium sulphate, calcium sulphate, and many others, in small quantities. These dissolved things not only make the water taste different from fresh water, but also make it different in many other ways.

Sea water is heavier than an amount of fresh water that takes up the same room. This can easily be shown by using a small bottle, closed with a glass stopper which is pierced by a fine hole, as shown in Fig. 96. We weigh the bottle empty and then fill it with fresh water and put in the stopper. Some of the water runs out through the hole, so that, after we have carefully wiped the outside of the bottle, we have it full right up to the top of the hole. We now weigh again, and when we subtract from this new weight the weight of the bottle alone we have the weight of the water. We then do the same thing with sea water: the form of the

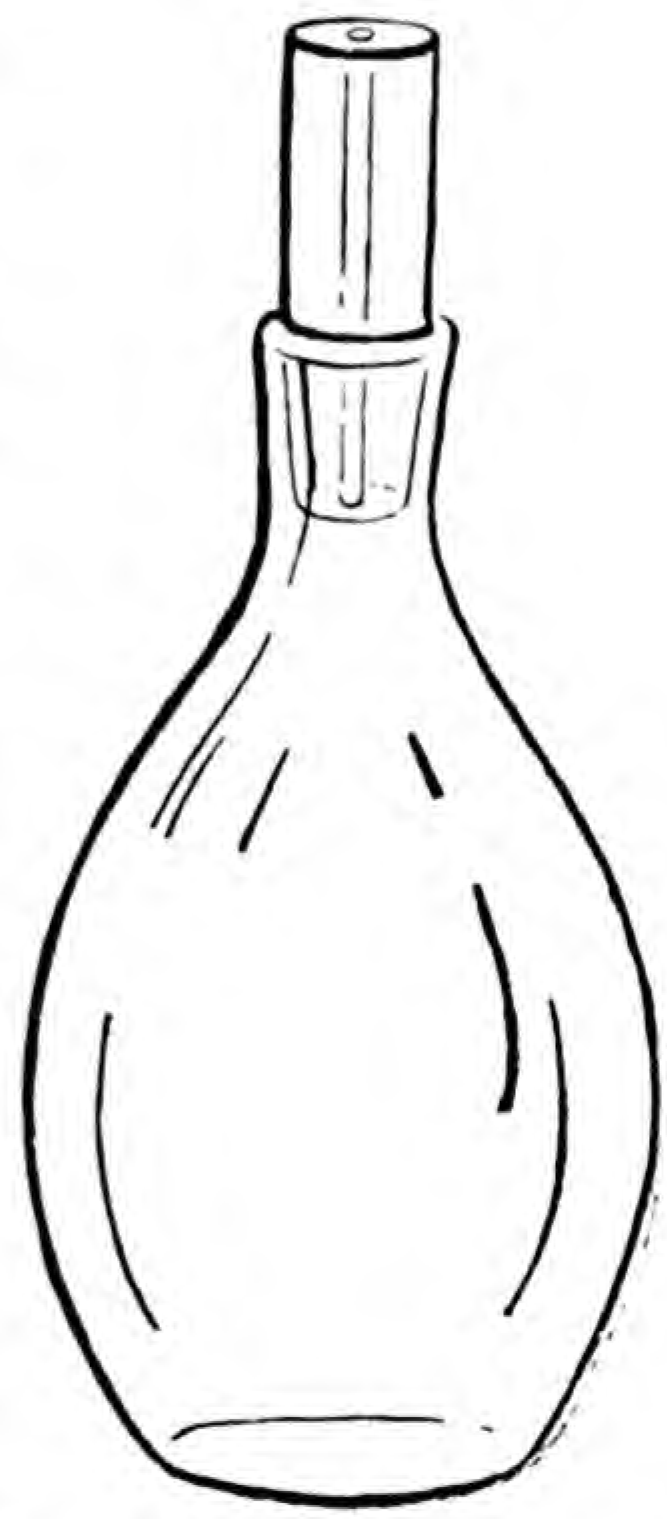


Fig. 96.— *A bottle for weighing an exact volume of liquid. It is called a density bottle.*

stopper makes sure that we have just the same volume of water as before. It will be found that, if the flask holds 25 cubic centimetres, which is a convenient size, the sea water will be about half a gram the heavier of the two. The exact weight will depend upon the amount of salt dissolved in the water, which varies in different seas.

We can also show very quickly that sea water is heavier than fresh water by an instrument known as the hydrometer. One form of this instrument consists of a glass tube provided with a narrow neck marked out with a scale: the tube is weighted inside with small shot or with mercury, so that it floats with its neck sticking partly out of the water. If it is put into a heavier liquid it will float higher. By noticing just how high the level of the water stands on the neck it can be found in a moment that the sea water is denser than the fresh. The neck of the hydrometer is usually marked with divisions. An instrument of this kind is used for testing the acid in accumulators, for when the acid gets too weak it becomes lighter and the instrument sinks deeper. Hydrometers are also used for testing milk and other liquids.

Not only hydrometers, but, of course, anything else that floats in water will float higher in sea water. Any swimmer knows that it is easier to float in the sea than in a river, and easier to swim, because the body floats higher. At Droitwich in Worcestershire, near the salt mines, there are salt baths where the water contains very much more salt than at any seaside resort. In these baths a man can sit down in the water, and so float, with his head and neck above water. A ship that is loaded at a dock in fresh water will float a little higher in the sea, and, since warm water is lighter than cold water, will float higher in winter than in summer. The Plimsoll mark on the side of

a ship, which must by law be not lower than the water level when the ship has her cargo on board, has therefore several lines. In the mark shown in the picture FW stands

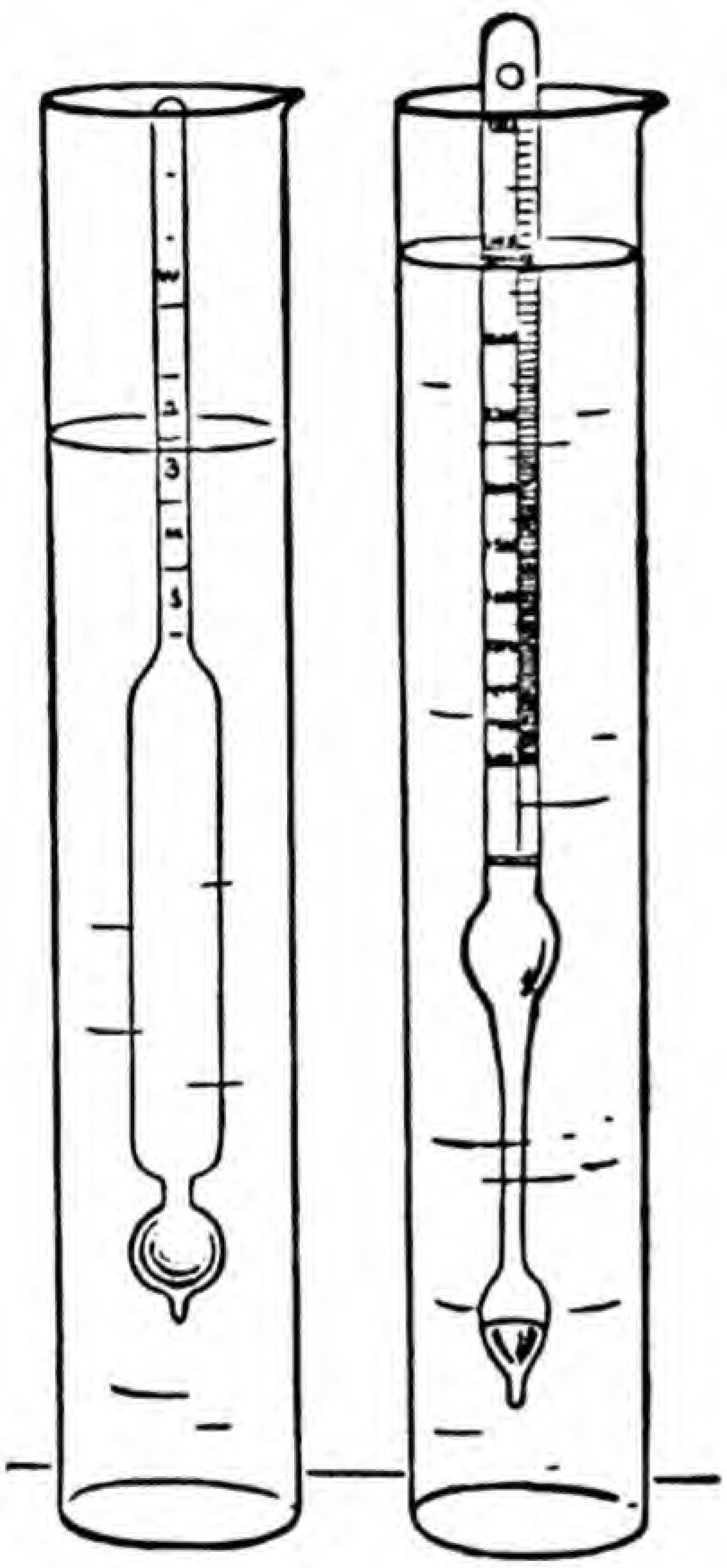


FIG. 97. — *Hydrometers. That on the right can be used for any liquid heavier than water; that on the left is the special form made for testing milk, sometimes called a lactometer.*

FIG. 98. — *The Plimsoll mark, showing the different lines for Fresh Water, Indian Ocean in Summer, and sea in Summer and in Winter. In the picture the Plimsoll mark is a long way above the water because the ship has no cargo (L R means Lloyd's Register.)*

for Fresh Water, IS for Indian Ocean in Summer, S for Summer, W for Winter. Sometimes WNA for Winter North Atlantic is added.

Another very important difference between salt water and fresh water is that water with salts of any kind dissolved in it cannot be frozen as easily as fresh water. The freezing point of pure water is 32° on the Fahrenheit scale, or 0° on the Centigrade scale. The freezing point of water containing as much salt as it will hold is 22 Centigrade degrees below the freezing point of pure water. The freezing point of the water depends upon how much salt it contains, which varies in different parts of the ocean, but it is always a few degrees below that of fresh water. If the sea were fresh water many ports that are actually open all through the winter would be frozen up. In the Baltic, for instance, the freezing point is round about 3° Centigrade below that of fresh water, and in winter the sea is open some 250 or 300 miles further east than it would be if the water were fresh.

In the refrigerating industry advantage is taken of the fact that strong brine[1] will not freeze unless it is very much colder than the temperature at which pure water freezes. To preserve meat and other eatables from going bad there are, at the docks, for instance, very large cold-storage rooms where the temperature is always below freezing point. In the engine house are large refrigerating machines which can produce cooling effects; the problem is to spread the cooling effect over the whole space. This is done by having water pipes all round the rooms, through which brine, made very cold by the machines, is made to pass. Water could not be used, for it would freeze at once, but strong brine remains still liquid even at the very low temperatures needed.

[1] Water with salt dissolved in it is called brine.

The Density of Water and Ice

By the density of any substance we mean the weight of a piece of a certain fixed size. We may choose the size to be a cubic foot, and measure the weight in pounds, or we may take the weight in grams of a piece 1 centimetre cube in size. There are, roughly $28\frac{1}{3}$ grams to the ounce, and just over $2\frac{1}{2}$ centimetres to the inch.[1] We must always say what size and what weights we are using. Thus, if we say that the density of a particular kind of iron is 7·8 grams per cubic centimetre we mean that a piece of iron 1 centimetre cube weighs 7·8 grams. This is the same thing as a density of 487 lbs. per cubic foot.

As in all scientific work grams are used for weighing and centimetres for measuring lengths, we will now say a word about these measures. Besides the centimetre we have, for larger lengths, the metre, which is 100 centimetres, and the kilometre, which is 1,000 metres, which makes a metre about $3\frac{1}{3}$ inches more than a yard, and a kilometre ·62 of a mile. If we do not need to be very exact we may take it, when comparing kilometres and miles, that 8 kilometres make 5 miles. The kilogram, which is 1,000 grams, is used for weighing heavy things: it is about $2\frac{1}{5}$ lbs., so that on the Continent, where the kilogram is used for selling things in shops, as well as in science, if you buy half a kilogram of anything you get a little more than an English pound.

The system of weights and measures based on the gram and the metre is called the metric system, and was started by the French in 1801. To fix the measure of length, they decided that the metre should be one ten-millionth part of the shortest distance from the pole to the equator,

[1] More exactly 28·35 grams to the ounce, and 2·540 centimetres to the inch.

measured along the surface of the earth. The centimetre is one hundredth part of the metre, and for their scale of weights they decided on the weight of 1 cubic centimetre of water. That is how the system was fixed. The weight of a piece of water which takes up a certain space, for instance the 1 cubic centimetre which we have just mentioned, depends, however, upon how hot the water is, and so we have to consider how water behaves when heated.

Fig. 99.—*The meridian (A B) through Paris. The metre is one ten-millionth part of the length of this line.*

Hot water is lighter than cold. The boiling of water in a test tube held at the bottom, described on page 13, is only possible because the hot water, being light, stays at the top. If we hold the tube at the top and heat it at the bottom we cannot bear it for long, since the hot water from the bottom at once rises to the top, which becomes uncomfortably warm. For the same reason if some cold water is carefully poured on the top of hot water in a tube it sinks at once to the bottom, but if hot water is poured on to cold, it stays at the top. This can be shown by colouring the water with a little red ink. It must be poured very carefully and slowly down a rod, so that it does not splash. With the hot water red we can arrange a red layer on top of the uncoloured water, but we cannot arrange a white layer on top of red water.

Now let us consider what takes place in winter with a river or a pond. The earth at any depth cools very slowly as the cold weather comes, so that while the air is very cold the earth surrounding the bed of the river is much warmer. The water at and near the surface of the pond therefore gets colder than the rest of the water, and sinks at once to the bottom, leaving slightly warmer water, which in its turn gets cold and sinks. The cold water, once at the bottom, stays there until some still colder water from the surface comes down. The surface will never get really colder than the rest of the pond, for the moment the water is just a little bit colder it sinks. If this went on right down to the point where the water froze the whole pond would, by this mixing process, soon reach the freezing point, and become a solid block of ice. We know, however, that the pond only freezes at the surface, which means that there must be warmer water below. How can this happen?

The explanation lies in a very peculiar behaviour of water. As the water cools it becomes heavier and heavier, it is true, but only up to a certain point—that is, until the temperature has fallen to 4 degrees Centigrade (written 4° C.) above zero, zero Centigrade being the temperature at which pure water freezes. If the water now gets colder still, strange to say it begins to expand, and goes on expanding until the freezing point is reached, so that although water a little above 4° C. is a little lighter than water at 4° C., water a little below 4° C. is also a little lighter. At 4° C. water has its greatest density. The gram was fixed to be the weight of 1 cubic centimetre of water at 4° C.

Now let us consider the effect of this fact that water has its greatest density at 4° C. on the behaviour of our pond

in winter. Until the surface of the pond has fallen to 4° C. all will take place as described above, and owing to the fact that the water falls as soon as it cools all the pond will be pretty nearly at 4° C. Suppose the surface cools further. Water below 4° C. is lighter than water at 4° C., and so will stay at the top. As it cools it gets lighter still, so that the pond, at 4° C., is covered with a layer of colder water, which freezes as it reaches 0° C. A layer of ice therefore forms over the top of the pond, and the water just underneath, which is nearly freezing, being lighter than the still warmer water deeper down, stays where it is. The layer of ice may gradually get a little thicker, from the top, but the bottom of the pond, which has the warmest water, never gets colder than 4° C. and so never freezes. This fact, which is of the greatest importance for fishes and other things that live in lakes and rivers, is due to water behaving differently from other liquids, which get heavier and heavier as they are cooled right down to the point at which they freeze, and do not reach a point where the change of density reverses.

When water turns from a liquid into solid ice, it suddenly expands by about a tenth of its size, so that the ice is lighter than ice-cold water, as we know at once from the fact that it floats. That is why water pipes burst when the water freezes in them, for it is the frost that bursts them, not the thaw as many people think During the frost no one notices that the pipe is burst, for it is full of ice which is solid and does not leak out. As soon as the thaw comes the ice melts and the water runs out of the pipe, so that the leak is noticed. To avoid the bursting of pipes during a frost they must either be protected, where they run outside the house, with straw or felt, so

that they do not get very cold, or else, if they are lead pipes, they can be hammered slightly flat, as shown in Fig. 100. If this is done the expansion when the water turns to ice just forces the pipe out towards the round shape again, and does not split it.

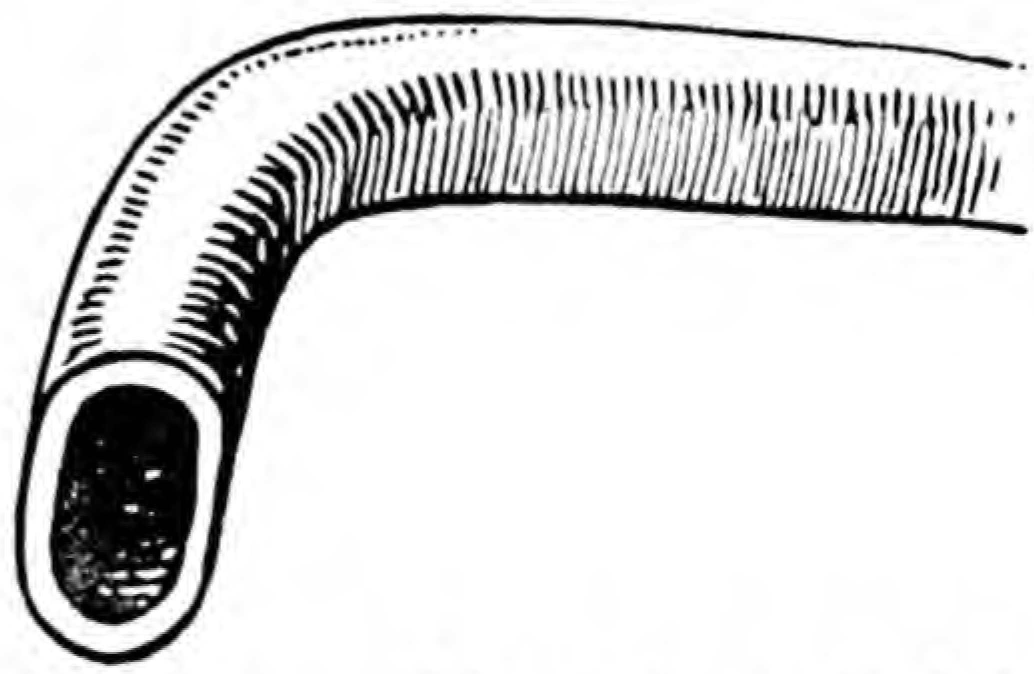


FIG. 100.—*A lead pipe, which has been hammered flat to prevent it bursting when the water freezes.*

An instructive experiment was made by an artillery officer at Quebec many years ago. He filled with water a large round iron bombshell, about 14 inches across, of the kind that was used in his time, and closed it by driving in firmly an iron peg. The bombshell was then exposed to the frost. The stopper was soon driven out and

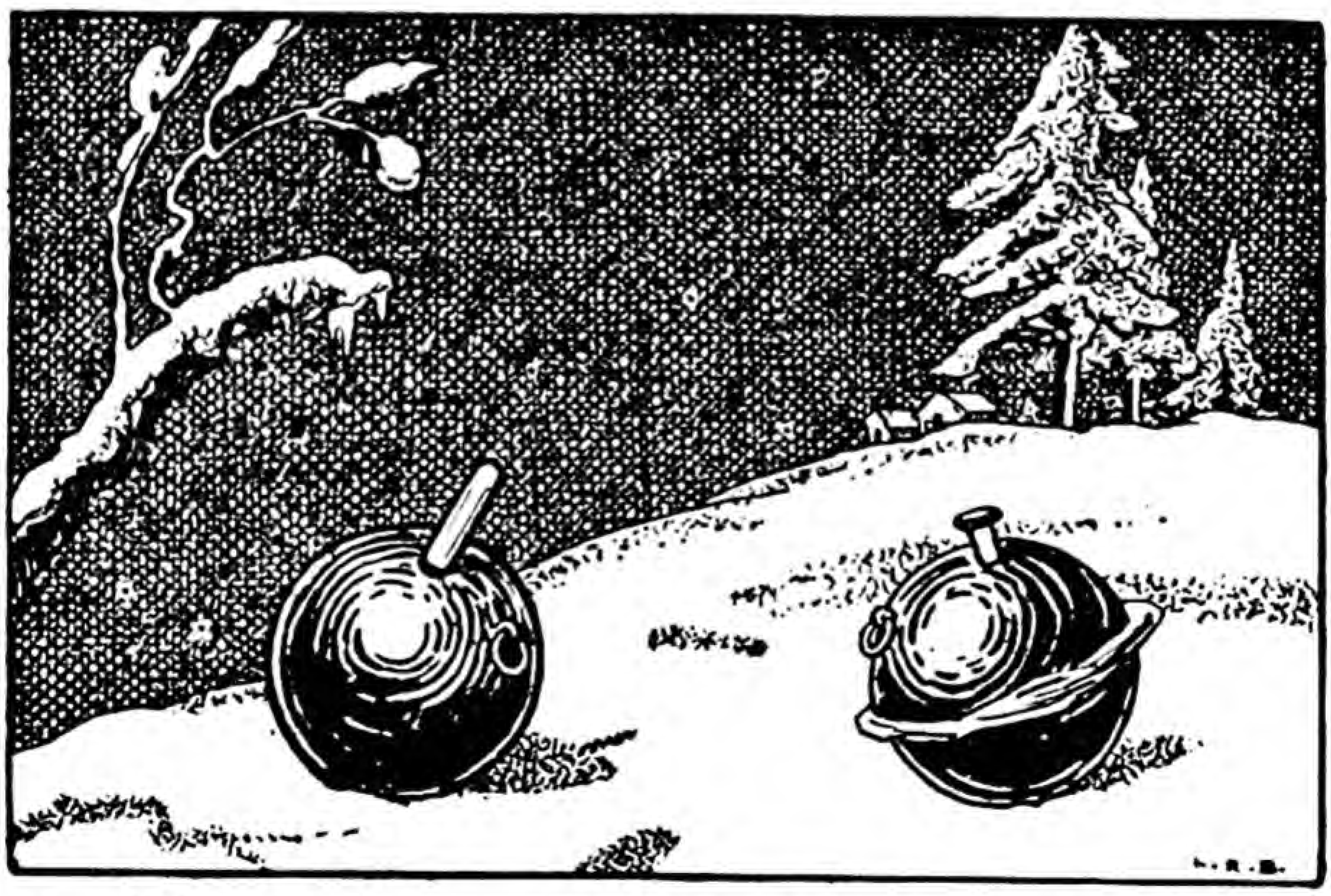


FIG. 101.—*The experiment made at Quebec with bombs filled with water and tightly stoppered. The water turning to ice in the bomb on the left has forced out the stopper; in the bomb on the right the stopper was very tightly fixed, and the bomb cracked.*

thrown to a distance of more than a hundred yards, while a rod of ice, 8 or 9 inches long, issued at the opening. On another occasion, when the stopper was driven in particularly firmly, the bomb cracked and a ring of ice was forced out, as shown in the picture. We can now easily understand that rocks into which water can penetrate may be split during a frost by the freezing of the water, and also how hard clods of earth are broken up in the same way during winter, a fact very important for the farmer. On the tops of many mountains, such as Scawfell Pike in England, or the Eggishorn and Sparrenhorn in Switzerland, an extraordinary wreckage of rocks split by ice can be found. As the great man of science, Tyndall, who was also a keen mountaineer, has said: "Under the guise of freezing water, a giant stonebreaker has been at work upon the heights."

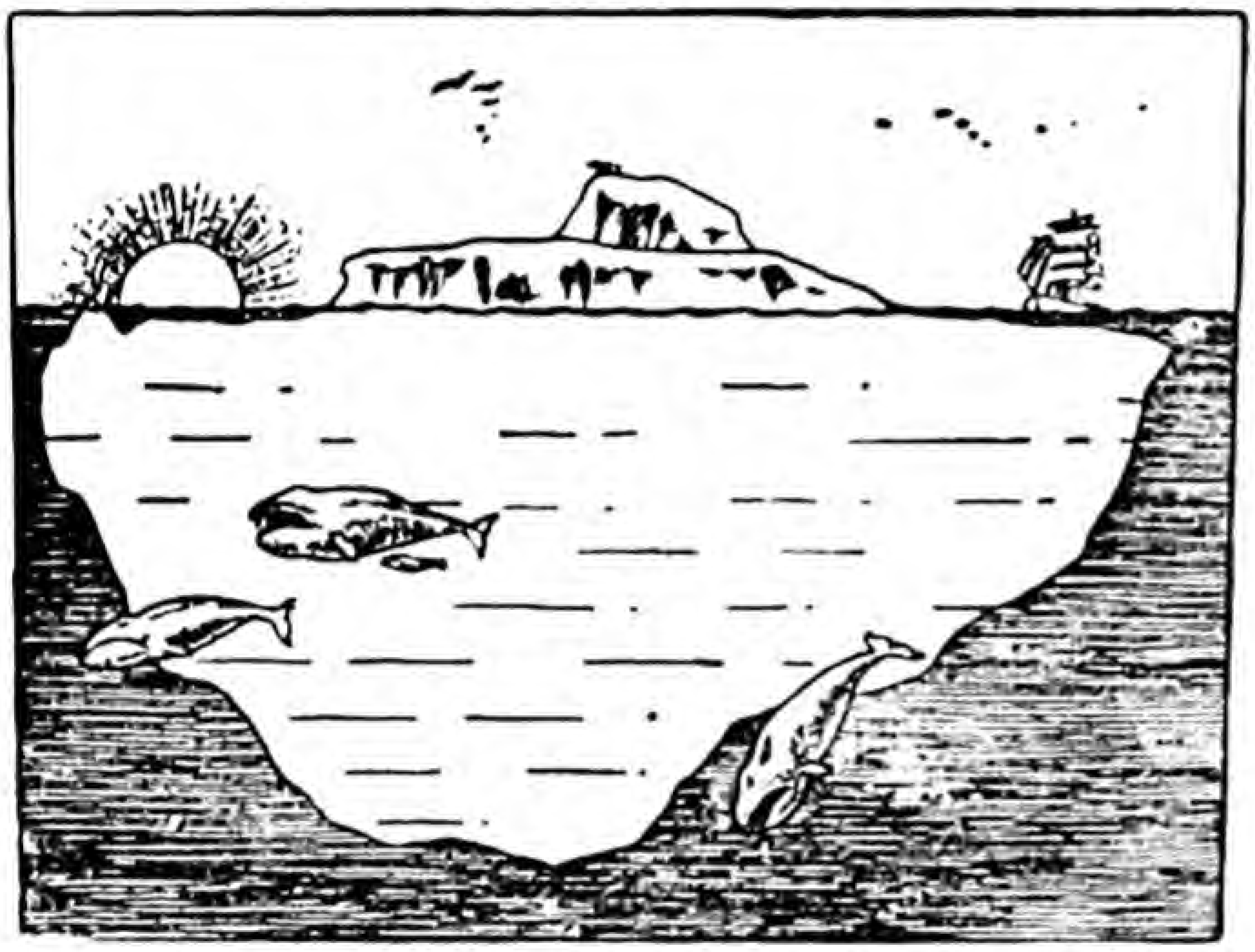


FIG. 102.—*An iceberg, showing that about nine-tenths are under water when it floats.*

Ice floats on water with about one-tenth of its bulk above the surface. An iceberg, which is nothing but an enormous block of ice which has broken away from a glacier or large ice-sheet somewhere in the Arctic or Antarctic, and floated into warmer seas, is therefore mostly under water. Ships' captains know this well, and give icebergs a wide berth. Not only may there be parts just under the surface of the water a long way from the parts which show, as in the picture, but as the under

part melts away in the warmer seas, the whole bulk may suddenly turn over, as a ship would if a large piece were sliced off under the water.

Some other liquids behave like water and expand when they go solid, but most of them shrink when they solidify. Liquid cast iron and liquid type-metal are among the few that expand, which means that they make good castings, for they swell out into every cranny of the mould when they go solid.

What is Water Made of?

Strangely enough, water, which is a liquid, is made of two gases, called oxygen and hydrogen, combined together. We will first of all see how it is possible to show this by experiment, and then try to go a little further towards understanding the nature of the combination.

Water can be broken up, or decomposed, as it is called, in a vessel like that shown in the picture, consisting of two tubes joined together by a cross tube, and closed each one at the top by a glass tap. In each tube is a strip of the metal platinum, fastened to a wire which passes through the glass. Platinum is used because, even when electricity is sent through it, it does not undergo any change in the water, as most other metals do. However often we do the experiment the platinum always remains the same in amount and appearance. The tubes are filled with water right up to the taps. The experiment works better if a drop or two of acid, say sulphuric acid, is added to the water.

The wires to the platinum strips are now joined to the terminals of an electric battery—six large dry cells or three accumulator cells are suitable. As soon as this is done bubbles begin to appear at the platinum, and to rise to the

top of the tubes, displacing the water. After five or ten minutes there will be a fair amount of gas collected in each tube, but much more in the tube joined to the negative pole of the battery (marked –, or painted blue) than to that connected to the positive pole (marked +, or painted red). If the tubes are marked so that the amounts of gas can be read off, it will be found that the proportions are about two of gas from the negative to one of gas from the positive pole.

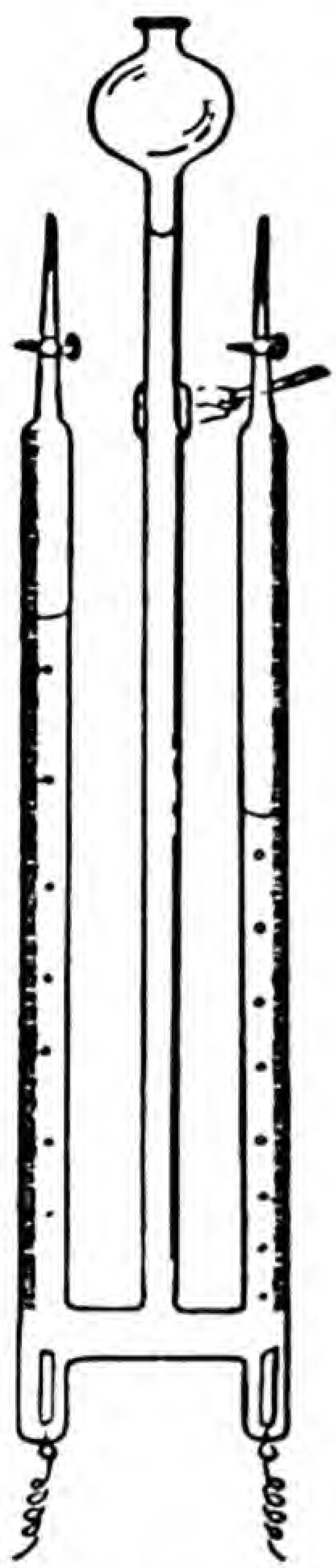


FIG. 103.—*The apparatus for splitting up water by electricity.*

To test the two gases, hold a match close to the top of the tube containing the negative pole, and open the tap carefully. A little blue flame will appear and burn at the opening: the tube contains a gas which burns just as ordinary coal gas does. The flame will not last long, as there is not really much gas there. Very soon the water, pressing out the gas, will have risen to the tap, which should be closed at once to prevent an overflow. At the top of the other tube hold a splinter of wood which has been lit and blown out so as to leave a glowing edge. When the tap is opened the splinter will burst into flame, but the gas will not light. If a flame is held over the tube it will merely flare when the tap is opened, but still the gas will not light.

The gas which burns is hydrogen. Although the burning of *pure* hydrogen is seldom seen except as a laboratory experiment, use is widely made of the hot flame which it gives, for ordinary coal gas contains a large quantity of

hydrogen. The gas which makes the glowing splinter burst into flame is oxygen. The experiment shows us, then, that water can be broken up into oxygen and hydrogen.

A simple experiment is now required to form water from oxygen and hydrogen. A good supply of hydrogen is easily made by putting some pieces of granulated zinc into a flask and pouring on them sulphuric acid. The neck of the bottle is then closed with a cork, which has been pierced and provided with a tube to lead off the gas. It is just as well to have a little bulb in the tube, filled loosely with cotton-wool, to stop any acid spray. After a minute or two, to allow all the air to be swept out of the bottle, we can light the hydrogen, which burns exactly as did the hydrogen released from water by electricity. We now arrange over the flame (but not too close, as the flame is exceedingly hot) a funnel bent over and passing into a wide glass tube so that the hot air rising from the flame is led into the tube. Very soon the tube becomes cloudy inside, and in a short time drops can be seen moving down the sides, and collecting in little pools. These drops are pure water, which have come from the hydrogen flame. The oxygen in the air has combined with the hydrogen, forming water actually in the flame, but it is so hot here that it is in the form of dry invisible steam. This steam rises with the air, and as soon as it has gone far enough to cool down it turns to drops of water, just like the steam from a kettle spout.

As a matter of fact, water can just as well be produced from a candle flame or a gas flame or a coal or wood fire burning in air. If a flask containing cold water is held well above any such flame, say a gas flame, it will soon become clouded, and then covered with drops. A cold

spoon can be used instead of the flask of cold water, or a lump of metal, but these objects soon become warm, so that the moisture is driven off again. These flames produce water because candle, and coal gas, and coal, and wood all contain hydrogen, which combines with the oxygen of the air to form water. However, since these other combustibles contain other things as well as hydrogen, they produce other things besides water when burnt. Hydrogen is the only thing in nature which furnishes nothing weighable except water when it burns in air. All flames produce heat, and hydrogen in particular gives a very hot flame. Heat, however, is not something which we can weigh, but a form of energy.

Oxygen and hydrogen can, then, join together to form water, and the electrical experiment shows that the proportions are two of hydrogen to one of oxygen, measured by the space which they take up under similar conditions. A volume of hydrogen only weighs one-sixteenth as much as the same volume of oxygen (at the same pressure and temperature), so that if we speak of weights it is eight of oxygen to one of hydrogen. It seems strange that two gases do not make a gas, but a liquid, and if the gases were just mixed they would, indeed, just be a gas. It is when they are joined together, as by burning, that we get water.

Chemical Compounds and Mechanical Mixtures

Water, then, is composed of two gases, oxygen and hydrogen, combined together in such a way that they give out energy, in the form of heat, when they join; if they are already joined they require energy (for example, the electrical form of energy which we used) to separate them. Air also consists of gases, chiefly the two gases oxygen

and nitrogen, although there are small quantities of carbon dioxide and other gases there as well. There is, however, a most important difference between the case of water and the case of air, a difference which is expressed in a scientific way by saying that water is a chemical compound, and air is a mixture. Let us see what is meant by these words.

In the first place, in the case of a mixture, such as air, the thing produced by the mixing has just the properties which we should expect from the things mixed. If we mix two[1] gases, we have a gas; if we mix two liquids, a liquid; if we mix two solids, such as sand and sugar, a solid. The density of the mixture is something in between the densities of the two things mixed. Taking air as our example, oxygen allows things to burn very vigorously in it, nitrogen does not let them burn at all, and the mixture lets them burn, but not nearly as vigorously as pure oxygen.

In the case of a compound, like water, the result is nothing like the two bodies which combine. Water is a liquid, and the two bodies which combine to form it are gases; it takes up only a very small fraction of the space which they occupy. Another example of a compound is common cooking salt, which is chemically called sodium chloride, and is made of the solid sodium, which is a soft metal, and the gas chlorine, which is green and choking. Sugar is another compound, made up of charcoal, oxygen, and hydrogen, which, if just mixed, would certainly not taste sweet.

The bodies in a compound are joined together in such a close and peculiar way that their separate properties are

[1] For simplicity, we shall only speak of two substances, though larger numbers are often found in both mixtures and compounds.

quite hidden, but in a mixture they just lie side by side, and their properties show through. The effect of this is that it is much easier to separate out the parts of a mixture than of a compound. A mixture of salt and sand is easily separated by dissolving and filtering, as described in Chapter II. A mixture of sand, sawdust, and iron filings can be separated by using a magnet which pulls out the iron from among the rest of the powder, and then by dropping it on water, when the sawdust floats and the sand sinks. Mixtures of gases are more troublesome to separate, but it can be done without chemical means. With a compound, on the other hand, we cannot take advantage of the physical properties of the separate parts to separate them. Iron, which is a familiar metal, and sulphur, which is a light yellow solid, combine to form the brass-coloured crystals called iron pyrites, which are often seen in coal, and called fool's gold, because hopeful people mistake them for the precious metal, but no magnet, however powerful, will pull the iron away from the sulphur with which it is combined.

Another difference between a mixture and a chemical compound is that in the compound the bodies which make it up are always joined in perfectly definite and fixed proportions. In water there are always two parts by volume of hydrogen to one of oxygen. In common salt there are always 46 parts of sodium to 71 parts, by weight, of chlorine. By no possible means can we make a kind of water with just a little more hydrogen or a little more oxygen than usual. If we put too much hydrogen into the oxygen, the extra hydrogen will be left over, as hydrogen, when the oxygen and hydrogen combine to make water. In a mixture, however, we can arrange the proportions to be as we like. If in a room we mix some extra

oxygen, we shall have a slightly different kind of air, which supports a flame just a little better than ordinary air. The composition of the air even varies a little as we go up. Although it is much the same seven miles up as it is at the surface, owing to the mixing produced by air currents, at ten miles up the air is roughly 80 per cent. nitrogen and 19 per cent. oxygen, instead of 78 per cent. nitrogen and 21 per cent. oxygen, as it is at the surface, and higher still it is even richer in nitrogen, but it is still air. All kinds of pure water are, however, exactly the same. In a chemical compound the proportions never alter, wherever the compound is found or however it is made.

We can, perhaps, make the difference between compound and mixture quite clear by a simple illustration. In a crowded amusement park at holiday times men and women are mixed anyhow. If a few more men or a few more women enter they soon become merged in the crowd, which looks very little different. A dance hall, however, presents quite a different appearance. Here the men and women are arranged in pairs, or combined, as we may say. The thing that strikes anyone glancing quickly down from a gallery is a number of moving things, each of which moves quite differently from a man or a woman alone: it is a man dancing with a woman. If a few extra men alone or a few extra women alone enter the hall they cannot come on to the floor and enter into the dance. Even if a dance were invented in which two men danced with one woman the proportions of number of men to number of women on the dance floor would still be fixed, and could not be altered a little one way or the other. The dancing people represent a compound; the jostling people outside the hall, a mixture. Or we may take an example from folk dancing, where men and women are

arranged in dancing groups of four or eight. There must be just so many men and so many women to make up the groups, which correspond to chemical compounds, and if a few odd men or women are present they must remain over.

The science of chemistry is occupied with studying how to put chemical compounds together, and how to take them apart. Many years ago that was the only task, but today we know that the changes of energy which accompany the building up and breaking down of compounds are just as important, both from the point of view of scientific interest and from the industrial point of view, as the rules for making the compounds. The heat which is given out when oxygen and hydrogen combine to form water is only one example of the kind of thing that takes place whenever bodies truly combine. Chemistry and electricity and chemistry and heat have to be studied together if we are to become masters of our materials.

CHAPTER VII

LIFE

PLANTS AND ANIMALS

EVERYBODY knows what we mean when we say that a man or an animal or a bird or an insect is alive. These living things move and breathe and eat; they grow and they repair themselves to a certain extent. Cuts, for instance, heal up if they are not too bad, and even fresh finger-nails can be grown to replace damaged ones. Plants also are alive. They, too, grow and repair themselves: they breathe and they eat, though not in the same ways as animals or insects—in fact, it may be better to say that they require and take in food than to say that they eat. Ordinary plants, however, do not move about, and at first it might seem quite simple to tell a plant from an animal by this test. Quite likely you think that it is absurd to talk about telling plants from animals, as if there were any difficulty or doubt. If you think of a cat and a cabbage, there is certainly no doubt which belongs to the animal kingdom and which to the vegetable kingdom.

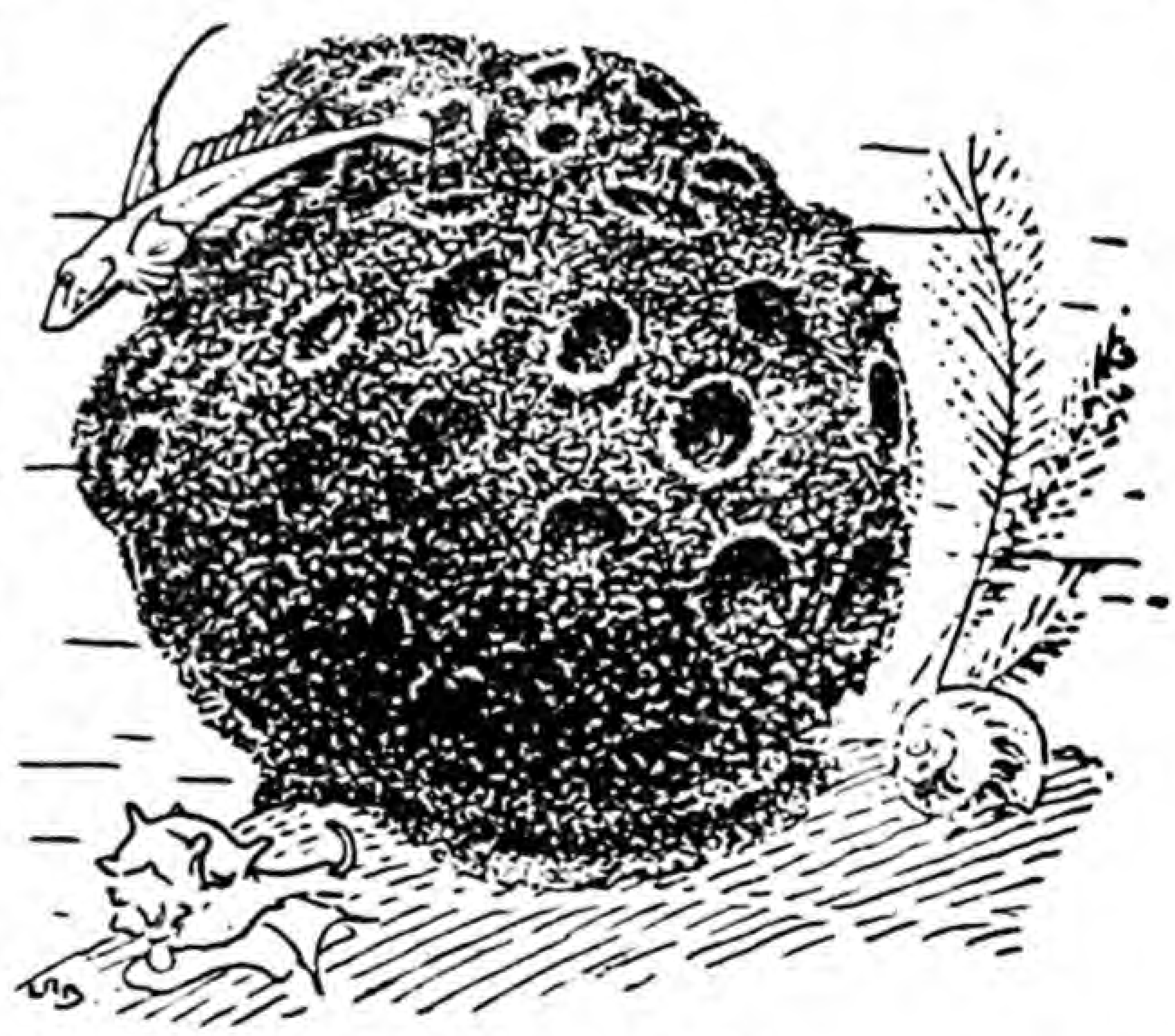


FIG. 104.—*A living bath sponge, as it appears on the floor of the sea.*

Things are not, however, always as simple as that. The sponges with which we wash ourselves are parts of things which once were living. Fastened to rocks in the Mediterranean Sea may be found the masses which afterwards become our bath sponges, but all the sponge that we know is then covered with a living jelly, provided with waving threads, like tiny whip-lashes, which urge the water through the passages of the sponge. The living sponge lives by filtering tiny bodies, which are its food,

FIG. 105.—*Sea anemones. They are not a kind of flower, but a kind of animal.*

from the water. The sponge in our bathroom is the skeleton of a living thing, all the soft jelly substance having been cleared away before the sponge is marketed. It is a skeleton made, not of bone, but of a substance something like silk, called spongin, yet a skeleton for all that. Now, which is a sponge, a plant or an animal, if we have to call it one or the other? It grows on a rock, and you might feel inclined to call it a sea plant, but it is actually an animal. Why it is so we shall see later.

In rock pools at the seaside there are often beautifully coloured sea anemones, each of which is like a lump of

tough jelly with a crown of delicate branches waving in the water. If the water runs out of the pool the branches all fall back on to the main part of the anemone, and the whole thing loses its gay appearance, and looks like a dull lump of jelly. You might think that the anemone was a sea

FIG. 106.—*The plant sundew, which catches and absorbs insects.*

plant like seaweed, especially as a land anemone is a flower. Although it appears to grow on the rock it is, however, a sea animal, which can actually creep about a little by expanding and contracting its root or base, somewhat as a snail does, but more aimlessly. If a prawn or a little fish swims against the anemone's tentacles it is caught by them, and pushed through a hole in the middle

of the tentacles into the creature's stomach, where it is digested. It is, then, not always so easy to say what is a plant, what an animal, especially when we consider the queer habits of some plants. A little plant which grows in marshy ground, called the sundew, has leaves which are covered on top with threads or tentacles, as they are sometimes called. Each tentacle bears a large drop of sticky fluid, which looks like dew, whence the name of the plant. If an insect, say a fly, settles on the leaf, it sticks, and the tentacles bend and pass the fly on to other tentacles until it arrives at the middle of the leaf, where it is held by the curving arms until it is drowned by the liquid. The soft parts of the insect are then digested by the juices of the plant, and serve to nourish it. This is very like the way in which sea anemones capture their food with their tentacles.

Growth

Just as it is not always so easy to say whether a living thing is an animal or a plant, so it is not quite so easy as it seemed at first to say what is the difference between a living thing and one that is not living. One property that seems to distinguish living things from non-living things is that living things, whether animals or plants, grow, while stones and bottles and bricks do not grow. Actually, however, many things that are not living grow. In some caves, and sometimes beneath old arches, long rocky formations, in shape like icicles, can be seen hanging from the roof, and others sticking up from the floor opposite them. Those from the roof are called stalactites and those pointing up from the floor are called stalagmites. They grow slowly until sometimes the stalactites meet the stalagmites and form one column. There is, however,

nothing living about these growths. They are formed by water, in which a mineral is dissolved, slowly trickling through a fine crack. The water evaporates, and the

FIG. 107.—*Stalactites and stalagmites.*

mineral is left as a stony deposit to which fresh trickles are always adding new layers. If the drops fall on the floor below, and the air is still, so that the drop always lands on the same place, a column is built up by evapora-

tion. The mineral is actually a particular substance called by the chemist calcium carbonate.

Calcium carbonate appears in many forms: chalk, mountain limestone, and coral are all calcium carbonate. Coral reefs grow slowly, like stalactites and stalagmites, but they too are not alive, although they are built up by living things, little animals something like very small sea anemones. It is their skeletons which make up the stone-like reefs that sometimes stretch for hundreds of

FIG. 108.—*A colony of corals and, in circle, a coral animal.*

miles, as does the Great Barrier Reef off north-eastern Australia.

Crystals also grow, and not only increase in size, but grow each one to its own particular kind of shape. We can, for instance, grow some crystals of sugar candy. We boil some water in a glass beaker (or a saucepan will do) and add sugar to it as long as any dissolves, taking care not to burn the syrup we make in this way. We now tie some bits of thin string to a stick, and arrange the stick across the beaker so that the strings hang into the

syrup. After some hours small crystals of sugar will be seen to have formed themselves round the strings. Next day the crystals will have grown larger, and in a few more days larger still. Although the mass of crystals on a string may take any shape, it will be seen that the single crystals that make up the mass all have the same shape.

A crystal can be made to grow by hanging it up in a solution of the same stuff as itself. For instance, a solution can be made with hot water and alum. If a crystal of alum is hung up in this, it will slowly grow larger, and little crystals will also form on the string. A piece of window glass can be prettily frosted over by brushing the glass with a hot solution of Epsom salts or alum: as the liquid cools, crystals will form, and can be seen to grow out from odd places where crystallisation has started. Another very pretty experiment can be performed by pushing a bundle of brass wires through a cork, and fastening a plate of zinc round the wires, or, better still, making the brass wires pass through holes bored in a piece of zinc. The wires are bent out a little, and the cork is then put in a bottle which has been quite filled with a solution of the substance called sugar of lead (which has nothing to do with sugar, but is what chemists call lead acetate: it has a sweet taste, but is

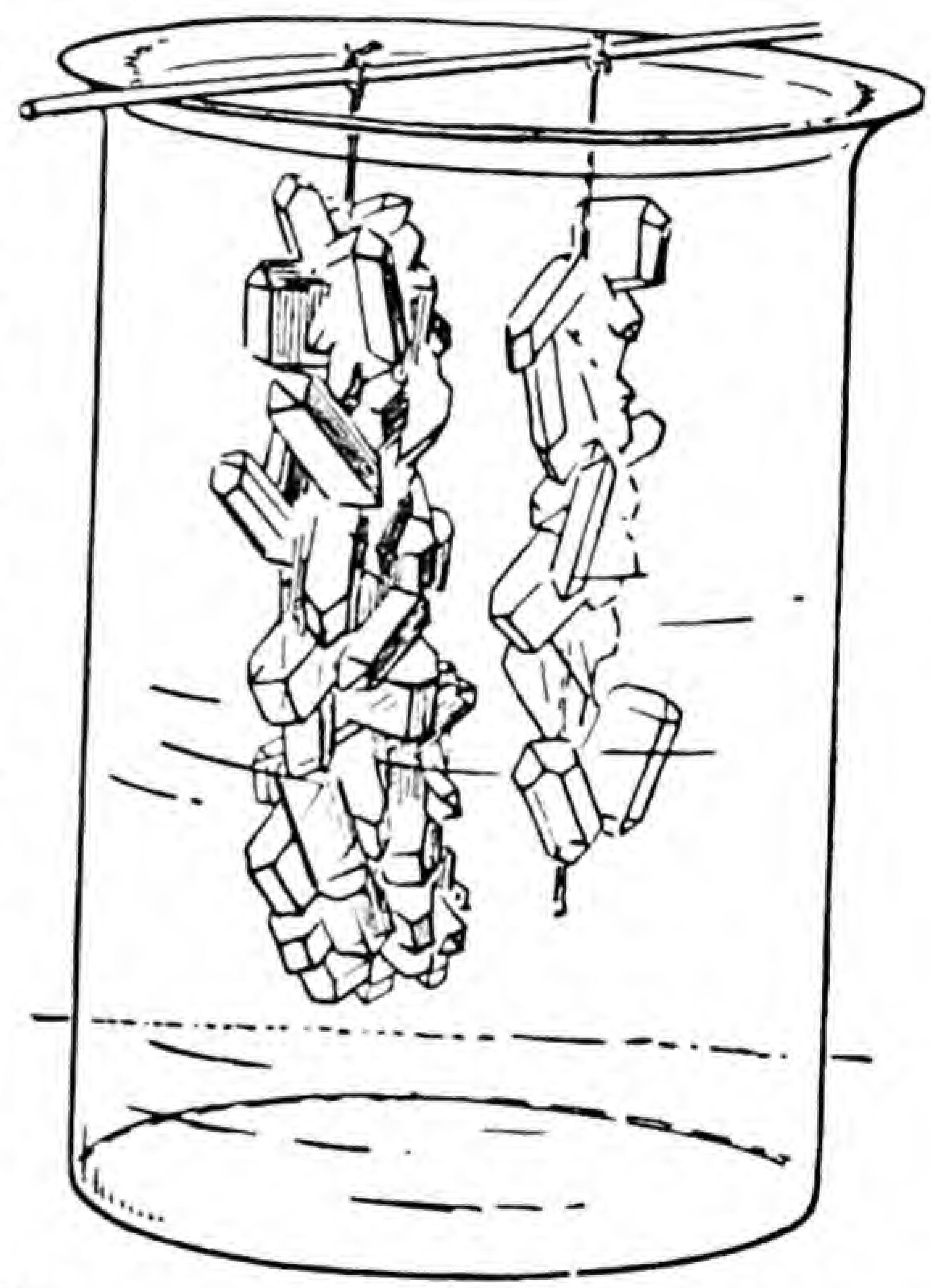


FIG. 109.—*Crystals of sugar-candy formed round strings.*

POISONOUS). The cork is sealed down and the bottle left. In a short time a little beautiful crystalline growth, like a tree, will form round the wires and spread more and more. This is a "lead tree," but it is not alive, although it grows bigger and bigger from day to day. Still another experiment, a very simple one this time, can be done by cleaning a little piece of aluminium with sandpaper and rubbing a few drops of quicksilver on it. Very soon little grey columns, like thick woolly

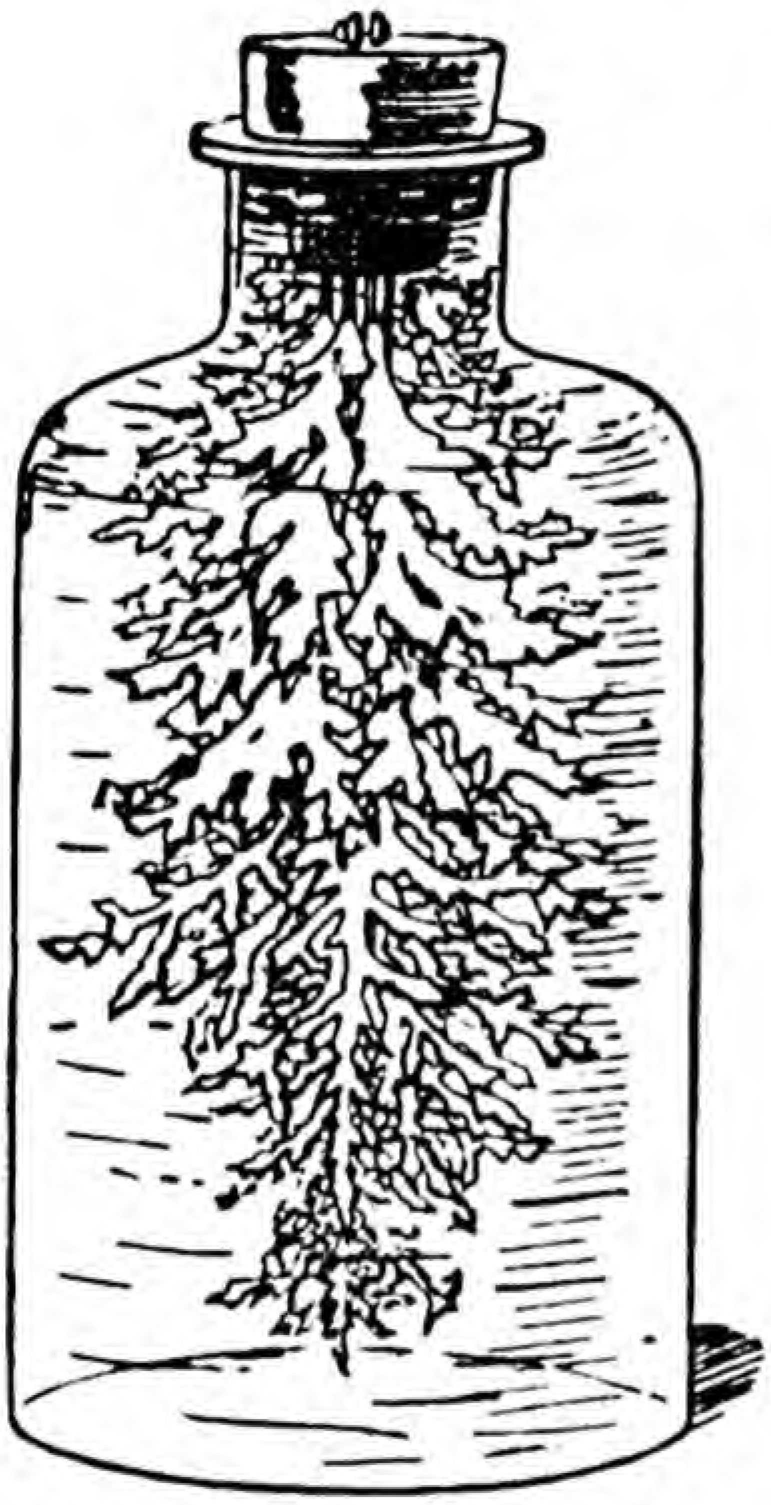


FIG. 110.—*The "lead tree" grown from a solution of lead acetate.*

FIG. 111.—*The growths on aluminium produced by a little mercury, slightly magnified.*

hairs, will start to grow from each little speck of quicksilver, and will get longer and longer until they stand half an inch or so above the aluminium. The aluminium grows whiskers, but it is not alive. All these experiments show us that crystals and other things can grow without being alive.

Is there, then, no difference between living things and non-living things, as far as growth is concerned? There is a difference. The stalactites and stalagmites simply add to themselves the limestone from the water. The crystals simply add to themselves their own kind of stuff

from the water in which it is dissolved. The lead tree is formed by lead coming out of the solution of lead acetate. The aluminium, when helped by the quicksilver in a way which we will not consider here, combines with the oxygen and water of the air to form the grey stuff which makes the hairs. The growth is simply a question of adding or combining with something which is touching the growing body; stuff is just added to the surface, and so the body grows bigger. This is not how even the simplest living things grow. They take some kind of food right into themselves, and turn it into something quite different from what it was—namely, part of their own bodies. They do not just add layers to their surface like crystals or the other non-living things we have considered: they have a wonderful way of making body-stuff from material of quite a different kind. This material is what we call their food.

Food

All animals must have food which they turn into the substance of their bodies. Some animals can go for a long time without eating; for instance, the dormouse, the hedgehog, and many kinds of bears and tortoises all hibernate, which means that they go to sleep in some hiding place all through the winter months, and, being asleep, naturally do not get any food, nor, in most cases is there any for them to get at this time of year. There are, however, two things to note about this hibernation. One is that the animals become very fat before they go to sleep, and the other is that while they are sleeping they are not only not moving about and working, but their very breathing slows down and becomes feeble. At the end of their sleep most of the fat has disappeared.

The animals store up food in the form of their own fat, and they hardly move at all, not as much as we do in our sleep, so that they need very little to keep them going. The camel is another animal which everybody knows can go for a long time without drink, but it is equally true and important that he can go for a long time without food. By the peculiar construction of his stomach he can store water, but he also has a hump (some species two humps) which contains a store of fat on which he can draw when he has no food, just as if he were carrying about hay outside him instead of fat inside him. When he has been working hard or unable to get good food, his hump becomes small and flabby. Here again, then, the animal is only able to go without food because he has a store within him.

The same kind of thing takes place with animals like pythons and leeches, which only need to eat every few weeks or even months. When they do eat they make an enormous meal, and then use it up very slowly. The little leaf-like creatures called flatworms which live in ponds and ditches can go without food for over a year, and so can sea anemones. In these cases the animal lives on itself. It needs food, and to get it manages to digest part of its own body, so that it grows smaller and smaller.

We see, then, that an animal is something like an engine, which needs a constant supply of fuel if it is to do work, but can do with very much less if it is just to keep running. A locomotive, for instance, needs far more coal if it is pulling a train than it requires if it is just running along the lines by itself. A warm-blooded animal, like a man or a cat, needs food partly to keep up his temperature, and partly to supply the energy for moving about and for working: he goes without food comfortably for

far longer when he is sleeping than when he is up and doing. Food is the animal's fuel. We are reminded of this when people, for fun, call eating "stoking up."

All animals feed, although they do not all bite off mouthfuls as men and most wild or domestic animals do. The gigantic whalebone whales have no teeth; their enormous mouths are provided with plates of whalebone fringed at the bottom, which hang down round the edge. As they swim they take in sea water and then drive it out through this sieve that surrounds the mouth. The

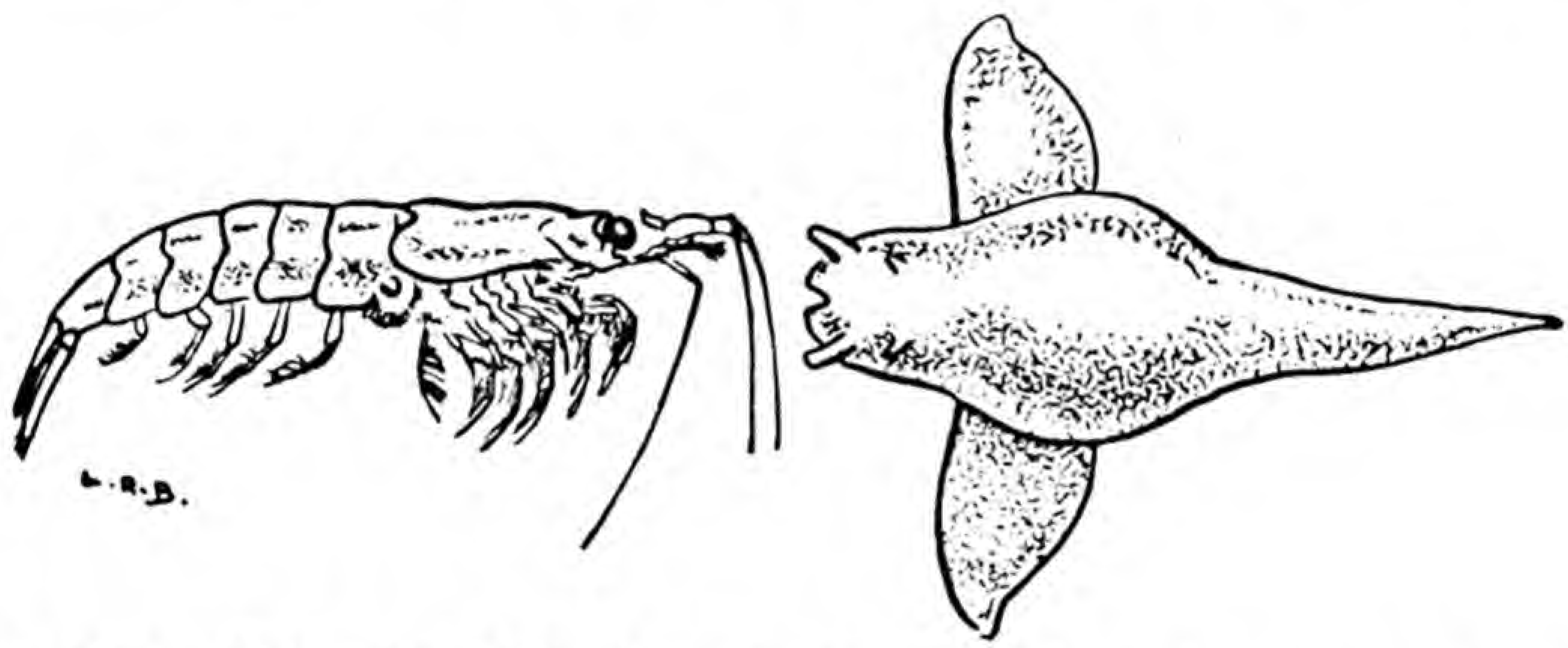


FIG. 112.—*The kind of food on which antarctic and arctic whales live. Natural size.*

sea is full of tiny shellfish, some about an inch long and some much smaller, which are caught in this way and eaten, so that the whale may be eating the whole time it is swimming. In the Antarctic the whales eat mostly a kind of shrimp. The little shellfish or shrimps in their turn eat much smaller brown floating plants, called diatoms, which require a microscope to see them. Most of the fish which we eat feed on small fish, which feed on tiny shellfish or shrimps, and these eat diatoms, so that we can say that the invisible diatoms are really the things that keep all the animal life of the sea going, just

as grass and other green plants keep all the animal life of the land going.

Worms have yet another way of feeding. They pass the earth and mud, in which they burrow, right through their bodies, as through a tube, and any stuff suitable for their food which may be in the mud is digested out and taken up by the walls of the tube. The earth or mud which is left over forms the "worm casts" which you can see on any lawn. Again, many animals take only liquid food. Mosquitos suck blood, plant-lice suck the juices of plants,

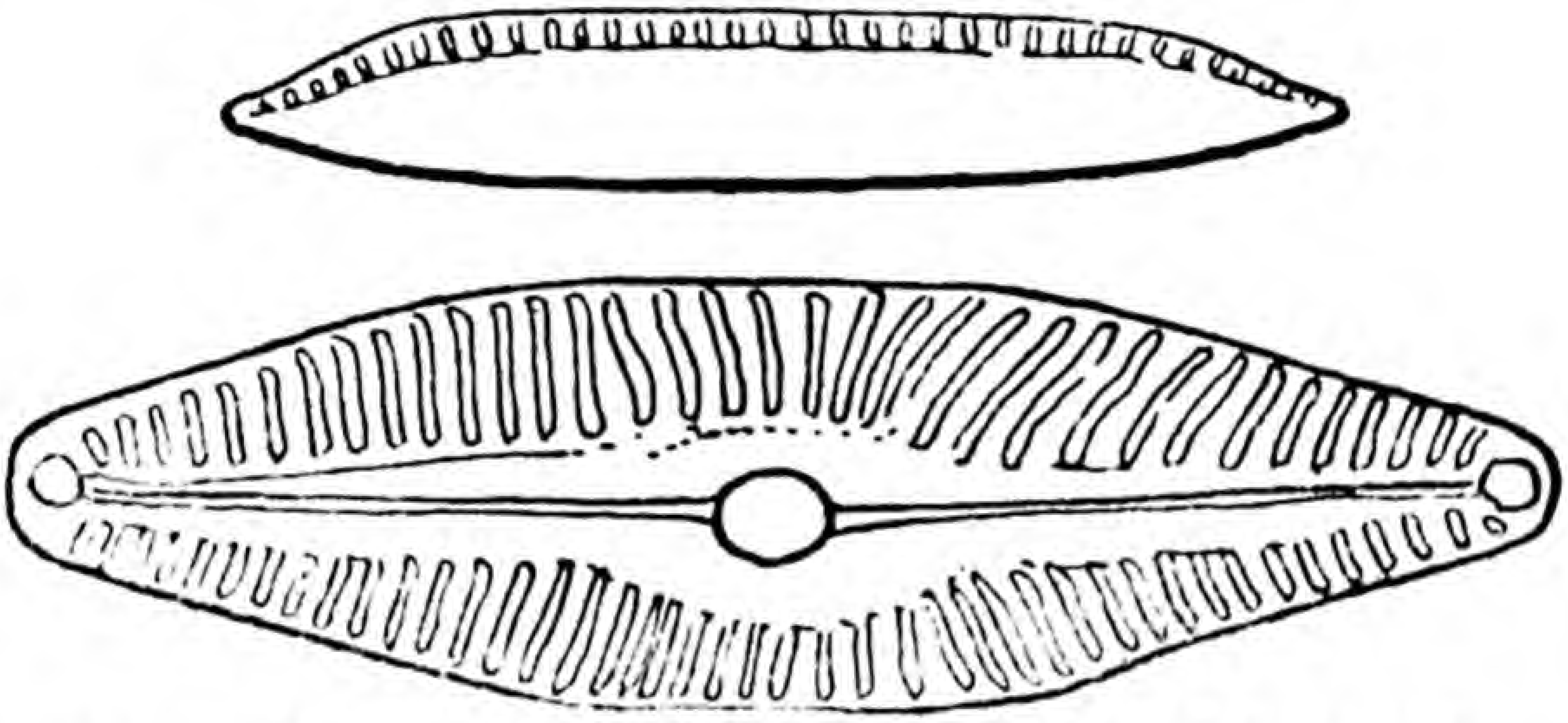


FIG. 113.—*Diatoms magnified to 500 times their real length.*

and babies, like other young mammals, live entirely on milk.

Some animals, as we have seen, remain anchored to one spot, as sponges and oysters and mussels do. Since these lazy organisms cannot go after their food they have to make the food come to them. This they do by means of little waving hairs, or cilia, of which we spoke in Chapter I. The moving cilia drive a current of sea water, carrying tiny particles of food, through the food-catching part of the animal—for instance, through the gills of the oyster, and through the pores of the sponge.

Still another way of getting food is used by parasites,

such as tapeworms which live inside animals. These have no mouths, but absorb all over the surface of their body food which the animal host has already digested.

Plants are also living things, and also require something to keep them going, but their food, if it may be so called,

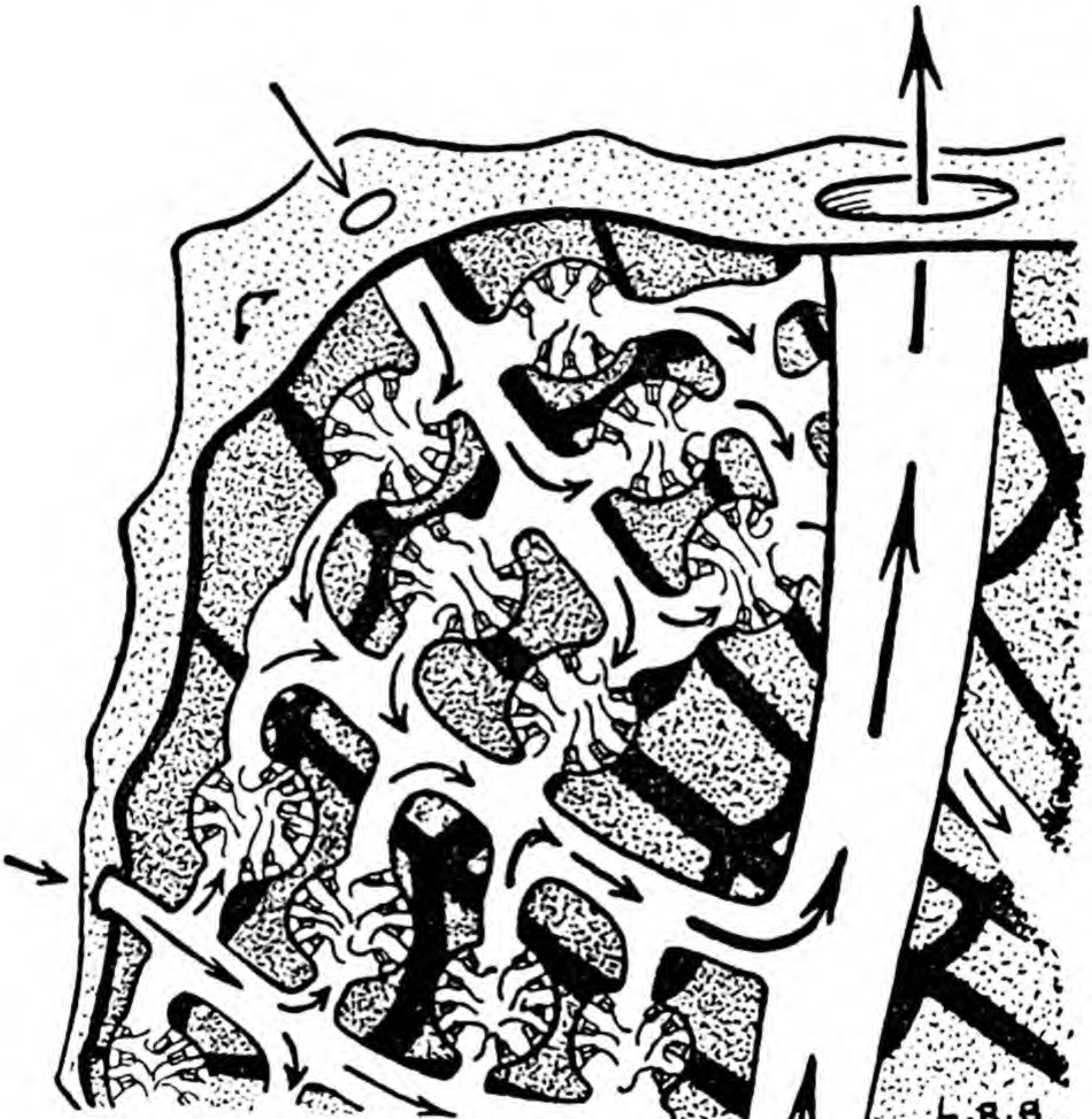


FIG. 114.—*A section of a piece of living sponge, showing the cilia which drive the water through the pores.*

is of quite a different kind from that of animals. The food of animals is other living things, or something made by other living things, whether it be diatoms, or fish, or grass, or milk, or fruit, or flies, or meat. The food of ordinary green plants is water and the gas carbon dioxide, which exists, as we have seen, in the atmosphere. How by means

of its green leaves, and with the help of sunlight, the plant is able to use this simple food to build up its substance is a matter about which we shall have to learn later. Plants also need nitrogen for their bodies, but this they do not take from the atmosphere, any more than a man, who also requires nitrogen, does. A man gets his nitrogen in other kinds of food, of which white of egg and lean meat are examples; the way in which the nitrogen is combined with other things in the food gives it a handle, so to speak, by which our bodily machinery can catch hold of it and deal with it, much as a man can use a knife blade combined with a handle, but not a knife blade alone, although that is what does the cutting, which is all he wants.

Plants, on the other hand, get most of their nitrogen from things like saltpetre, which come from decayed vegetable matter such as is in good soil, or from dead animals, or from manure, either natural or artificial. The important thing to remember is that plants need food as well as water, although as they have no mouths they need to deal with it in different ways. Vegetarians live on plants, but even people who eat meat are eating things that live on plant life, so that ultimately, as it says in the Bible, "All flesh is grass," meaning by grass any kind of plant life. In the end, then, our own life depends upon the wonderful way in which green leaves can build up plant food.

We can now see how to tell plants from animals. It is all a question of the kind of food which they need, and how they get it. The food of green plants is non-living matter, liquid or gas. Even the sundew, which seems to eat a live fly, actually only makes the fly rot on the surface of the leaf, and profits by the juices, just like a plant watered with liquid manure. Animals, on the other hand, take into themselves, usually in solid form, matter, either

animal or vegetable, which is either living or has recently been living. Plants take in their food nearly all over their body, while most animals have a mouth, or particular holes, for taking in their food, and some kind of a bag or stomach in which to digest it.

Men and Machines. Heredity

A man or other animal is very like a machine in many ways. The living animal requires its fuel, or food, as we have seen, and some animals by not working at all can do with hardly any food, just like a machine that is not working. We shall see later that muscles are in some respects like motor-car engines, the heart like a pump, the lungs like bellows, the arms like levers, and so on. In many ways, however, a man or animal is very unlike an engine, quite apart from the fact that engines do not think or feel or dream. Exercising the body, or a particular part of the body, by hard work makes a man or animal stronger, and the part that is most used develops most. The men with the strongest arms are those, like blacksmiths, who use them most. Constant use, however, does not strengthen a machine made of metal, but wears it out faster.

If a man or an animal is injured the part can repair itself, so long as the injury is not too serious: a cut finger heals, a bruised knee becomes well, and a broken bone can knit together again, if given a chance. Some animals can even grow a fresh limb to replace a lost one. A lizard can grow a new tail if it loses its old one, a newt can grow a leg, a starfish can grow a fresh ray, and crabs can grow a new claw. No engine can repair itself.

Growth itself is something that we do not find in machines, although, as we have seen, many things that are

not alive can grow. There is, however, one still more striking difference between all living things, even the simplest, and all machines, even the cleverest and most complicated. All living things have little ones that grow up like themselves, and so, although the individuals die, the race is carried on. Locomotive engines, however, never have a baby engine, and dead things, whether plants or animals, cannot have little ones either. The power of having little ones is called reproduction.

It is a very remarkable thing that animals and plants reproduce only their like. Black people have black children. Dogs only have puppies which become dogs, never kittens, and, what is more, certain kinds of dogs—say Great Danes—only have puppies that become that kind of dog, never Pomeranians. Collie dogs have puppies which become collie dogs. The seeds of any plant become that kind of plant. You can put ducks' eggs and hens' eggs in the same incubator, but the duck's eggs will always hatch into ducklings and the hens' eggs into chickens. These are things that everybody knows, but when we think how like in appearance the seeds of two different kinds of plants may be, say turnips and radishes, it is a marvellous thing that each particular seed has, locked up in it, the whole machinery for building up a new plant of one particular kind only. This likeness of the young living thing to its parents, whether animal or plant, is called heredity. Some people, for instance, are born with six fingers on their hands. The fact that this peculiarity runs in families is a striking example of heredity.

We can easily see, however, that, although in a general way the children are always like the parents, yet in details such as hair colour or eye colour they are often different. With garden peas a garden pea seed will always grow a

garden pea, but if we have crossed a tall-growing kind of pea with a dwarf kind of pea we get some seeds which give tall plants, others which give dwarf plants. At one time nothing was understood of the way in which this happened, but today rules have been found for this kind of heredity which have proved to be of wonderful importance, both for breeding domestic animals and for breeding the kind of fruit and flowers which we want. By studying these laws men of science have been able to grow a kind of wheat that resists certain very bad diseases that formerly often spoilt the wheat crop. They have been able to produce wonderful roses and sweet peas, and new fruits like the loganberry, which is a cross between a blackberry and a raspberry. They have been able to breed sugar canes that yield abundant sugar juice, but withstand the diseases that afflict ordinary kinds of cane.

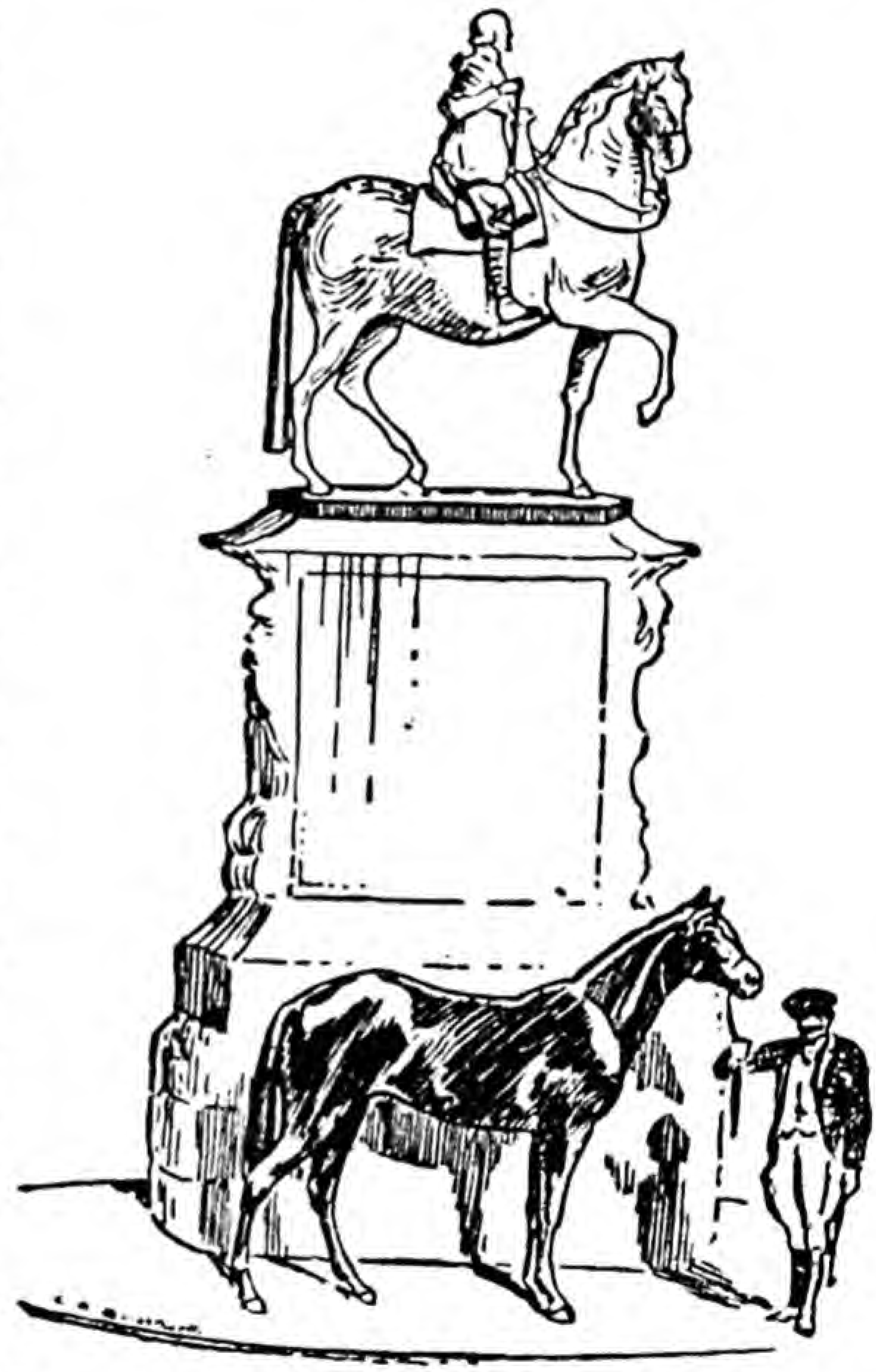


FIG. 115.—*The modern racehorse and King Charles I's horse, bred before Arab horses were brought to England.*

The racehorse gives us a very interesting example of heredity. At one time the horses in England were all stocky animals with short necks, like King Charles I's horse in the statue shown in the picture. Soon after the

year 1700 three Eastern horses were brought to England, which went by the names of the Byerly Turk, the Darley Arabian, and the Godolphin Barb. All the English thoroughbred racehorses are descended from one of these three horses, and they all have the same slender build inherited from them.

Plants which are not Green

So far we have spoken of plants which have green stuff in them, which they use to win their nourishment from the atmosphere. There are, however, many kinds of plants which are not green, and have to get their food by living on the decaying remains of plants or animals, or sometimes on a living plant or animal. The most familiar of these ungreen plants are the mushrooms and toadstools, which usually grow on richly manured ground. Another class of plants are the moulds, such as are often to be found on the top of a newly opened pot of jam, or on stale bread or stale cheese.

These moulds may not be very pleasant to the smell, but they are very interesting. They are really a kind of mushroom. The upper part of the mushroom, the stalk and "umbrella" which we eat, is only the fruit, so to speak. The real mushroom plant consists of the coils of long white threads which are attached to it beneath the soil. A mould is a similar tangle of white threads, and is simply a plant which is not green. There are many different kinds of moulds, just as there are many different kinds of toadstools, many of which toadstools, by the way, are very good to eat, although others are poisonous. The mould which grows on jam is not the same as that which grows on cheese, or on bread. Like mushrooms, these plants have no way of using light to help them take up carbon

dioxide from the air, for this cannot be done without green stuff, and therefore they need liquids containing, all ready manufactured, the food juices which they require. They find these juices in the things on which they grow.

Moulds do not, of course, themselves come from nothing. The air is full of little seeds and spores of different kinds, mostly, like those of the moulds, too small to be visible. These are always settling on things; if they find a suitable home they grow. When a spore of bread

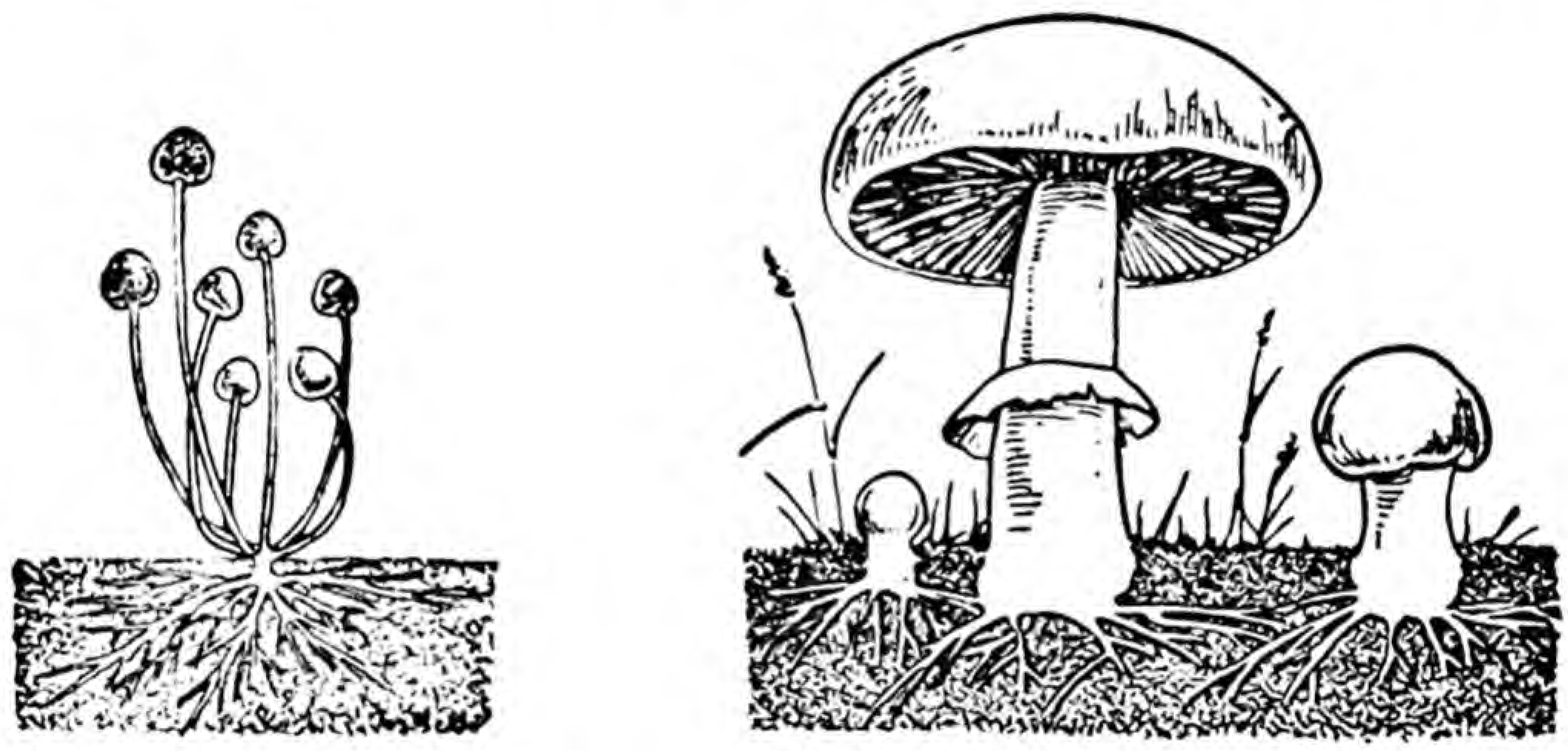


FIG. 116.—*On the left a bread mould, much magnified; on the right a common mushroom.*

mould settles on a piece of stale damp bread it finds itself at home, and grows rapidly. If it settles on a piece of new bread, or on fruit or meat, there is no suitable food for it, and nothing happens.

Both mushrooms and their like and moulds and their like are called *fungi*, which is the plural of the Latin word *fungus*, meaning a mushroom. There are many small fungi besides moulds, and most of them are very injurious, for they attack cultivated plants and crops. The potato fungus, the vine mildew, and the onion mould grow on and spoil the plants mentioned; the disease of wheat which

is called rust is another minute fungus, and the disease called smut, on account of the blackness it produces, is still another; and the mildews which attack roses and dahlias in particular are also tiny fungi, which, luckily, can be killed by spraying. The disease of ringworm, which attacks some children, is not due to a worm at all, but is a small fungus or mould: the victim is not attacked by a tiny burrowing worm, but by a minute mushroom.

There is a very important and particular kind of fungus which is called yeast. Everybody knows that yeast is used to make bread and cake "rise," but not everybody knows what yeast is. It looks dead enough when it is bought, as dead as the flour itself, or as knife powder, which it somewhat resembles. Actually, however, every grain of powdery yeast is a living organism, a little plant. The important thing about yeast for us is that, in nourishing itself on the flour or whatnot in which it may be put, it produces the gas carbon dioxide and also a certain amount of alcohol. In the case of bread the little bubbles of carbon dioxide blow up the bread, and make it light. Bread, however, is not the only thing in which yeast is used. There are many kinds of yeasts, just as there are many kinds of moulds, and a different sort from the bread sort helps to turn grape juice into wine, and still another sort to turn apple-juice into cider. While the grape sort and the apple sort are usually on the skin of the fruit all ready to do their work, the kind of yeast which turns malt into beer has to be put in specially. It is called brewers' yeast.

FIG. 117.—*Yeast cells, on left; on the right a section of a human hair to the same scale, to give size.*

GERMS OF DISEASES. STERILIZATION

Yeast cells are very small, only a hundredth of an inch across or less, but there are many much smaller organisms which have a great influence on our lives. We know that nothing comes from nothing, that, for instance, no mould grows on bread, however stale and damp, unless spores of that mould have settled on it from the atmosphere. We also know that a piece of tinned meat, say an ox tongue, does not go bad as long as it is shut up in the tin, but that if the tin is opened the meat will become offensive in a week or less, especially in hot weather. This would lead us to think that something had got at the meat from the atmosphere, and this is, in fact, what takes place. There is a large group of creatures which can only be seen through the microscope, some of which produce putrefaction, which means the process of becoming putrid or rotten. These creatures must be called ungreen plants, like moulds, if we have to decide whether they are plants or animals, but as they are so different from any other plants, even from moulds, it is better just to call them by their special name, which is bacteria, as mentioned in Chapter I.

There are thousands of different kinds of bacteria which can be examined by the microscope and recognised by the skilled bacteriologists, as people who make a special study of these things are called. Usually before the bacteria are put under the microscope they are stained with special dyes, to make them more easily seen. Some bacteria are exceedingly harmful, and produce diseases, others are very helpful, as it is by their aid that certain plants can get all the nitrogen which they need.

Bacteria can be grown, like ordinary plants, but the

soil, so to speak, on which they are grown, is usually either broth or jelly. Just like other plants, they follow the laws of heredity. The bacteria which accompany typhoid fever, grown on jelly, produce only bacteria of their own kind, which are, for instance, quite different from the bacteria of consumption, or of anthrax, or of lockjaw, which are shown in the picture 2,000 times longer than they actually are. Other quite different bacteria are of great importance in the making of cheese and butter: they are not deliberately put in, for cheese was made hundreds, if not thousands, of years before anybody knew anything about

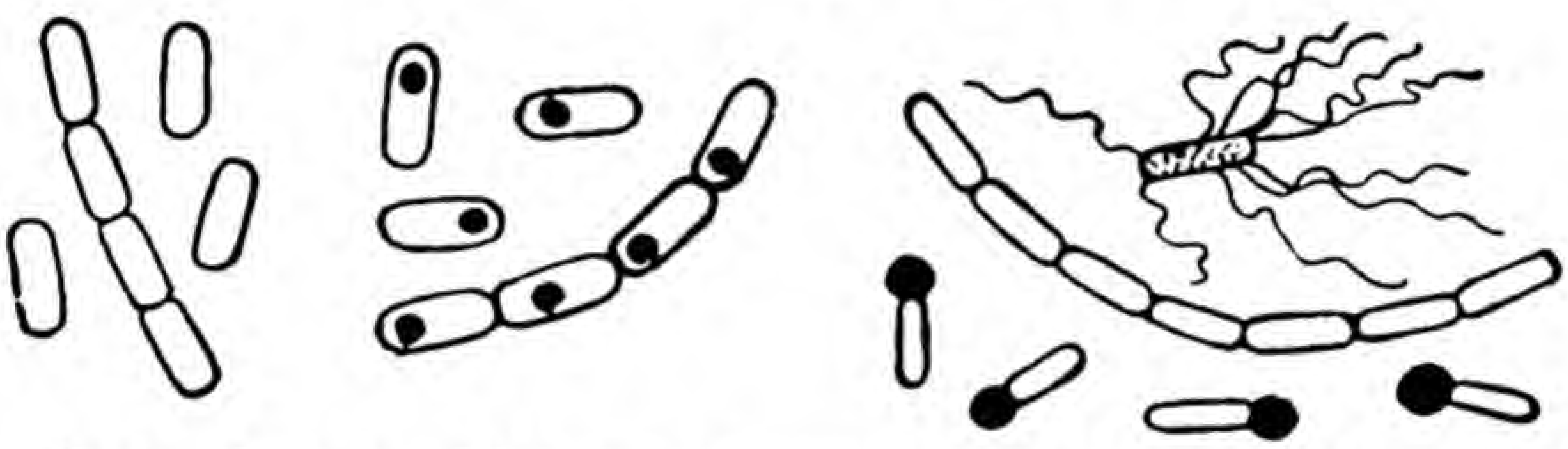


FIG. 118.—*Bacteria magnified 2,000 times. Those on the left are the bacteria of the disease anthrax, shown in two different stages; those on the right, of the disease lockjaw, shown in three different stages.*

bacteria, but scientific examination of what goes on in cheese-making shows that the bacteria do get in and that their work is needed if the cheese is to be made properly. All putrefaction is due to bacteria. The air is full of them, and so is water, so that we are always taking millions of them into ourselves. Our bodies are quite capable of dealing even with harmful bacteria, as long as there are not too many of them, but when, owing to their numbers or our weakness, one kind gets a footing in our blood, we become ill.

Luckily, harmful bacteria can be killed without taking them one by one and squashing them, for, as there are millions and millions of them, and they are too small to

squash by any ordinary means, that would be a poor way of waging war against them. Sunlight kills many of them, which is one of the reasons why light as well as air is necessary to keep a room healthy. A cinema into which no bright sunlight is ever admitted is not a healthy place, and many theatres have windows in the roof to let the light in when there is no performance. Disinfectants, such as carbolic and its products, also kill bacteria. But the easiest and most certain way, where it is possible, is to kill them by heat. No bacteria, no moulds, no seeds of any kind can remain living at the temperature of boiling water,[1] although they can withstand great cold. Of course, one cannot boil a sick man to kill the bacteria in his body, but one can boil, or heat in an oven surrounded by steam, surgical instruments, to make sure that there are no harmful living bacteria on them which would get into the body. This boiling is called sterilization. If a man, for instance, suspects that a razor with which he is going to shave has been previously used by an unhealthy person he can always guard against infection by steeping the blade for a few minutes in really boiling water.

If all putrefaction is caused by bacteria, then clearly if we can firstly kill all the bacteria in a piece of meat or fish, and secondly keep fresh ones from getting to it, the food will keep fresh. Actually this is what is done with tinned eatables. They are boiled in the tin, which is then soldered up while the contents are still hot. You can always see the little spot of solder with which the tin has been sealed. If by any chance the contents have not been kept hot long enough, so that a few bacteria have sur-

[1] There are, as a matter of fact, a few very hardy forms of bacteria that can withstand the temperature of boiling water, but even these are all killed at a rather higher temperature.

vived, these get to work, and the food goes bad in the tin. This ought never to happen, but if it does, gases are usually formed by the bacteria in their putrefactive work, and these gases bulge the tin. No one should ever touch food in a tin which shows any signs of being blown out from inside, or from which air comes out when a hole is made in the tin.

We see, then, that whether we look at great machines or mouldy bread, at the starry skies or the starfish, at magnets or steam or crystals of sugar, there is order and regularity, the study of which is science. Nothing is too ordinary to be interesting, if we try to find out the way in which it occurs, nothing is too small to matter, nothing too large for us to try and understand. In this book we have looked at some of the subjects which fall within the range of science, and learnt the first beginnings of that knowledge of their working which has been found out by the patient study of great men in the past.

QUESTIONS AND EXERCISES

CHAPTER I

1. Why cannot the stars be seen during the day? Draw a picture of the pole star and of the seven stars of the Great Bear on a piece of paper, and then, with the help of a pin, draw eight positions of the Great Bear, as seen at different times.

2. Write down a list of things made from (*a*) glass, (*b*) iron, (*c*) earthenware.

3. What are the uses of coal?

4. Say what you can about the following: (*a*) asbestos, (*b*) methylated spirit, (*c*) Arcturus, (*d*) a satellite?

5. What kind of processes are studied in chemistry? Make a list of substances known to you which are manufactured by the help of chemistry.

6. Obtain and draw the seed of a nasturtium, a sweet pea, and any third kind of flower. How is it that dandelions will often be found growing on waste ground in a city, but not nasturtiums?

7. What are the seeds of diseases called? Mention one or two ways in which they can be spread about.

8. Why is it natural for the biggest animal to be one living in water? Why is it natural for a snake to have a much longer and thinner backbone than a dog?

9. How could you show that sunlight, falling on them as they grow, changes the colour of (*a*) green vegetables, (*b*) fruit? Write down a list of the white vegetables which you know. Are any of them grown in the light?

CHAPTER II

1. Why does the chimney of a fireplace get full of soot, while the space over a gas stove never gets sooty? Write down a list of substances which, when burnt, produce soot. What does this tell us about the substances?

2. What do we mean when we say that true steam is invisible? What does a "cloud of steam" really consist of, and how does it differ from a cloud of smoke?

3. Write a short essay on "Gases and Their Uses."

4. How could you easily tell water from turpentine and from alcohol, if you had a bad cold and could not smell?

5. Describe some processes of manufacture which show that *solid* metals will flow if large enough forces are applied to them. What is the usual way of making metals flow?

6. How could mercury be used to separate out the gold from finely powdered rock containing specks of gold?

CHAPTER III

1. Explain clearly the difference between *work* and *power*. How much work does a sixty horse power engine do in ten hours?

2. Carry out an experiment to show that the two ends of a magnet behave in a different way, and write down exactly what you do and what you see. Try the effect of putting (1) a sheet of glass, (2) a large sheet of tin (which is really a sheet of iron covered with a thin coat of tin), between the pivoted magnet and the one in your hand.

3. What kinds of forces are those which can move things without any touching? Why do not the people in Australia fall off the earth?

4. How is it that an ordinary balance with weights would show the weight of a certain piece of iron to be the same in all parts of the world, whereas a very good spring balance would register differently at the Equator and in England?

5. Why does a piece of thin paper fall much more slowly than a stone? Carry out, and describe, an experiment with a flat stone and a piece of paper to prove that your explanation is correct.

6. Find the centre of gravity of a piece of thick board, and then, standing it on one edge on a plank that you can tilt, show that it falls over when the line through the centre of gravity falls outside the base.

7. Carry out the experiment shown in Fig. 58. Show that it will not work if the forks stick out straight (horizontally) on either side, and explain why this is.

CHAPTER IV

1. What different forms of energy do you know, and why are they called forms of energy?

2. Explain in what way it is true to say that coal provides both gas light and electric light in England. How is electricity produced without the use of coal in Switzerland?

3. What is meant by friction, and why do engineers want to make it as small as possible? How do they set about doing this?

4. What provides the energy to run (*a*) a modern clock, (*b*) a grandfather clock, (*c*) a watch, (*d*) a gramophone, (*e*) a windmill, (*f*) a water turbine, (*g*) a wireless set ?

5. How can oil be used to provide the energy for a steam engine ? How is it used in a Diesel engine ?

6. How can you show that sound takes time to travel, and how could you make a rough measurement of the speed of sound ?

7. How can the heat of the sun be made to run a steam engine, and why are such steam engines not commonly used ?

CHAPTER V

1. Draw a picture of a lighter-than-air and of a heavier-than-air aircraft, and explain the difference between the two. Which has to be the bigger if they are both to carry equal loads ?

2. Describe how the weight of air can be found. On what does it depend ?

3. Why is the pressure of the atmosphere greater at the earth's surface than at a mountain-top ? How could you show that there is such a difference of pressure ?

4. What experiment could you carry out to show why the condenser of a turbine engine must be made very strong ?

5. Explain with a drawing the way in which the automatic vacuum brake on a train acts.

6. What is the difference between an aneroid barometer and the other kind of barometer ? Which is the most convenient for carrying about, and why ?

7. Explain (1) why windows should be opened at the top, rather than at the bottom, to ventilate a room,

(2) why the wind generally blows off the sea to the land in the morning.

8. How can you show that the atmosphere contains water vapour ?

CHAPTER VI

1. Make a list of different classes of substances that contain water. How could you show that a piece of potato contains a quantity of water, and how could you try to find out just how much ?

2. Draw a picture of a still, and explain how it makes pure water. What is the difference between hard and soft water, and how could you tell one from the other ?

3. Draw a hydrometer, and say what it is used to measure. Why do people who charge accumulators have such an instrument ?

4. What is the Plimsoll mark, and why has it several lines ?

5. Hot water is left in the open on a winter's night and freezes to ice. Explain how its volume changes during the whole process. Why do people say that pipes burst during a thaw ?

6. How can you split up water into oxygen and hydrogen ? Why do we say that air is a mixture and that water is a chemical compound ?

CHAPTER VII

1. Give some examples of the growth of things that are not alive, and compare them with examples of the growth of living things.

2. Compare the appearance and habits of a sea-anemone with those of a land-anemone.

3. What do whalebone whales live on, and what do the creatures that form their food themselves live on?

4. How do the following feed: (*a*) trees, (*b*) cats, (*c*) sponges, (*d*) worms?

5. Write a short essay on heredity.

6. Discuss some ways in which a man is like, and is unlike, an engine.

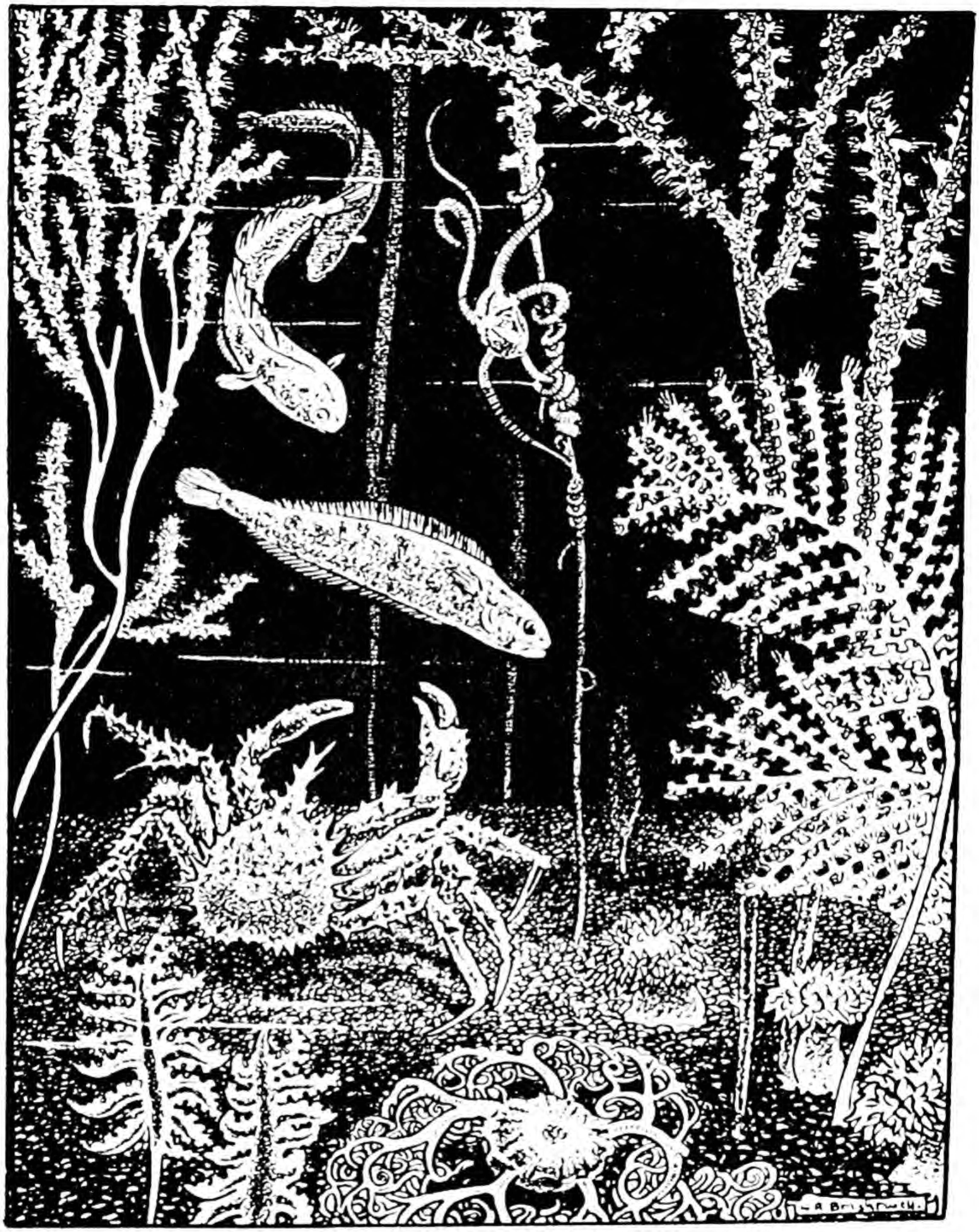
7. How do plants which are not green get their food? Is celery really a plant which is not green?

8. How can you kill the germs of disease and decay? Why does tinning keep things fresh?

Printed in Great Britain by
Billing and Sons Ltd., Guildford and Esher

ANDRADE AND HUXLEY

AN INTRODUCTION TO SCIENCE



Life at the bottom of the sea (Chapter VII). *A scene at between* 100 *and* 200 *fathoms depth. The soft oozy sea-bottom is inhabited by growths of various kinds, composed of many small animals (polyps) living together. Crabs, brittle-stars, and sea-anemones are also shown, together with some fish swimming about through the plant-like polyp growths.*

AN INTRODUCTION TO SCIENCE
BOOK II

Science and Life

By E. N. DA C. ANDRADE
D.Sc., Ph.D., F.R.S.
Quain Professor of Physics in the University of London

and JULIAN HUXLEY, M.A.

With Drawings by L. R. BRIGHTWELL

BASIL BLACKWELL OXFORD

AN INTRODUCTION
TO SCIENCE

BOOK I. THINGS AROUND US

BOOK II. SCIENCE AND LIFE

BOOK III. FORCES AT WORK

BOOK IV. EARTH AND MAN

A practical handbook, price 10d., accompanies Books I, II and III

First printed January, 1933
Reprinted June, 1933
Reprinted September, 1933
Reprinted November, 1935
Reprinted October, 1938
Reprinted April, 1941
Reprinted April, 1944
Reprinted April, 1945
Reprinted June, 1946
Reprinted July, 1947
Reprinted September, 1949

CONTENTS

CONTENTS

CHAPTER VI

HOW PLANTS LIVE

CHAPTER VII

SOME DIFFERENT WAYS OF LIVING

CHAPTER I

BREATHING AND BURNING

Oxygen—Breathing is a Kind of Burning—Chemical Change—Burning and Energy—Different Ways of Breathing—Our Bodies are Slow-combustion Engines

OXYGEN

DAY and night, whatever else you may do, you are breathing. You breathe while you eat, while you work, while you play, even while you sleep. But do you ever stop to ask yourself *why* you breathe? I expect not; we all generally take everyday things for granted.

Why do we breathe? Why do we eat? Why do we sleep? Most people do not bother with such apparently simple questions. If they were asked, they would probably say they ate because they were hungry, slept because they were tired, breathed because they couldn't help it. And that is perfectly true—so far as it goes. But it only takes us one small step: it does not explain why we are made so that we need food, so that we want to sleep every night, or so that we can't help breathing.

It will be worth while to take this everyday fact of breathing and try to find out as much as possible about it. It will give us quite a new idea of living things. Our breathing, and that of all the animals we know, is the most obvious sign of being alive. It begins the moment we are born, and only stops when we die. We can make ourselves hold our breath for a certain time, but then we find ourselves forced to begin breathing again. If we are prevented from breathing for only a few minutes, we die.

That is why people drown if kept under water: it is not the presence of the water which kills them, but the absence of the air. Even when we are asleep or in a faint, our breathing goes on without our knowing anything about it. And the simplest way of seeing if a person is alive or dead is to hold something cold, like a mirror, in front of his mouth. If he is still breathing, the moisture in his warm breath will make the mirror grow cloudy: if it stays clear, his breath has stopped for ever.

About a hundred and fifty years ago, there lived a man called Joseph Priestley. He was a Unitarian minister; but he spent his spare time making chemical experiments. It was the time when people were making the startling discovery that there was not only one kind of air, but a great many different kinds—what we now call gases. And they had discovered the equally surprising fact that they could get gases out of liquids and out of solids.

In the first Part of this series, there was a description of getting one kind of gas by pouring hydrochloric acid on marble, another kind of gas from sulphuric acid and zinc. Even now it still seems surprising that in a hard solid stuff like marble substances lie hid which are released in the form of the gas carbon dioxide when the hydrochloric acid is added. And we can imagine how exciting it must have been in those days, especially as there was always the chance of discovering some quite new kind of gas.

Priestley tried heating various solid stuffs to see if this would make gases come off from them. He placed the substance on a little support and shut it up in a glass vessel which was filled with quicksilver and turned upside-down in a basin of quicksilver. He used a burning-glass a foot across to concentrate the heat of the sun's

rays on it (we spoke about burning-glasses on p. 92 of Book I). If any gas was given off it collected at the top of the jar, and the level of the quicksilver in it fell. He later used the method described on the next page (see Fig. 2) to collect the gases from heated substances.

One of the substances Priestley tried was a red powder which was known to contain the metal mercury—we now call it oxide of mercury. When he heated it, a kind of air was given off in plenty. He put a lighted candle into a bottle of this "air"; the candle became very bright, with a large flame, and burnt itself away much quicker than in ordinary air. A red-hot iron wire put into the gas glowed brighter and began to sparkle. Later, he tried an experiment with mice. If a mouse or any animal is shut up in an air-tight closed space—not just with the door shut, but a place with no cracks at all for air to get in, such as a tightly-stoppered bottle—after a time it will die. Priestley found that a mouse shut in a bottle of this new gas he had got from the red powder would live at least twice as long as in a bottle of the same size filled with air.

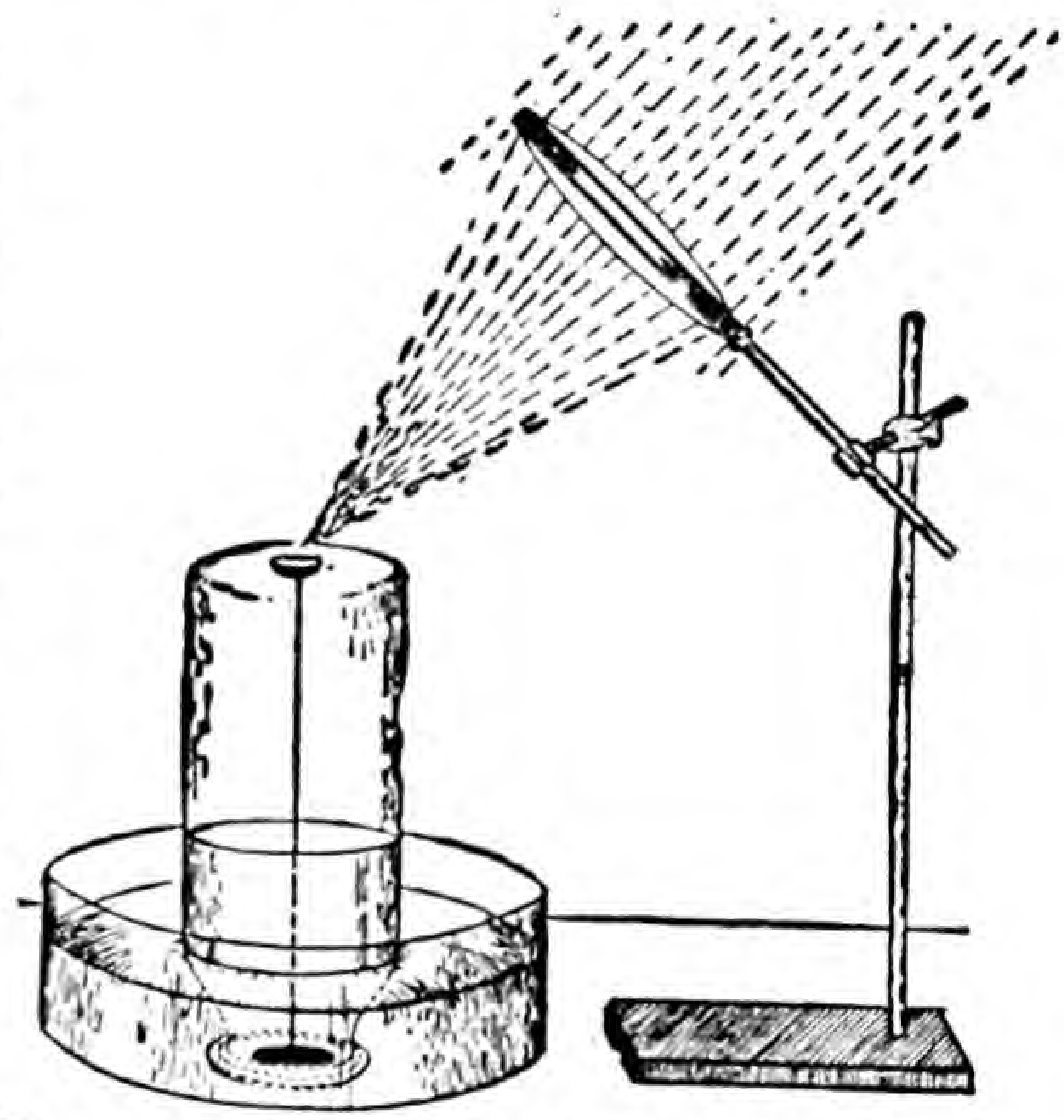


FIG. 1.—*How oxygen was first made. Priestley used a burning-glass to heat oxide of mercury. The oxide of mercury was in a metal saucer on a wire foot inside a jar. The jar was stood upside-down in a dish of mercury.*

You can make this gas for yourselves. An easy way

is to take some potassium chlorate and heat it in a tube of hard glass. (If you mix in a little manganese dioxide, the experiment will go much better.) A gas will come off, and you can collect it over water, as shown in the picture (Fig. 2). This is the same gas which Priestley obtained from oxide of mercury. Today we call it *oxygen*.

There is a great deal of oxygen in potassium chlorate, and very little heat is needed to bring it out. Even ordinary friction may set afire the lozenges made of potassium chlorate, mixed with sugar, which are used for sore throats. It has happened that such lozenges, carried loose in a cyclist's trousers pocket, have flared up owing to the heat caused by their rubbing together as his legs went up and down.

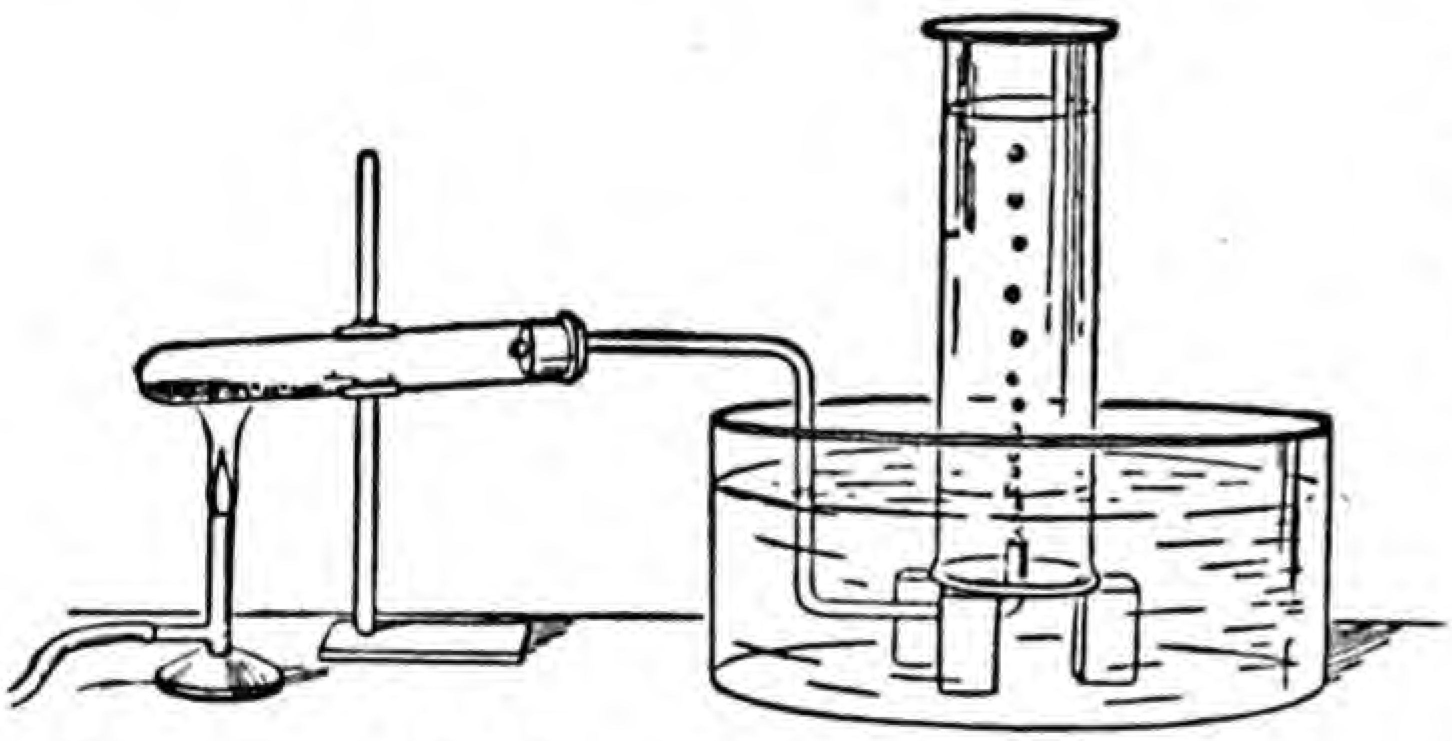


FIG. 2.—*Making oxygen from potassium chlorate.*

Potassium chlorate is also used in many fireworks, such as rockets, to give out a big supply of oxygen quickly. It is made into a powder with whatever is to be burnt, which is usually a mixture of substances containing carbon and substances containing sulphur. The powder is set on fire by lighting a touch-paper, so that after you have lit the firework, you can get safely away before it goes off. Once it is lit, plenty of oxygen is produced by the potassium chlorate, and so the other substances are burned very quickly, and while burning produce a quantity of hot gases. A rocket is made with a strong case which is sealed with paper at the bottom only, so that the gases

from the burning mixture can only escape at this end. The recoil as they escape is so great that it pushes the rocket violently in the opposite direction, and shoots it up into the sky. (We shall explain about recoil in the next chapter.)

You can put a candle-end into the oxygen you have made and see it burn brighter; or you can light a match, blow it out, and if it is still glowing, it will brighten and burst into flame when you put it in the oxygen.

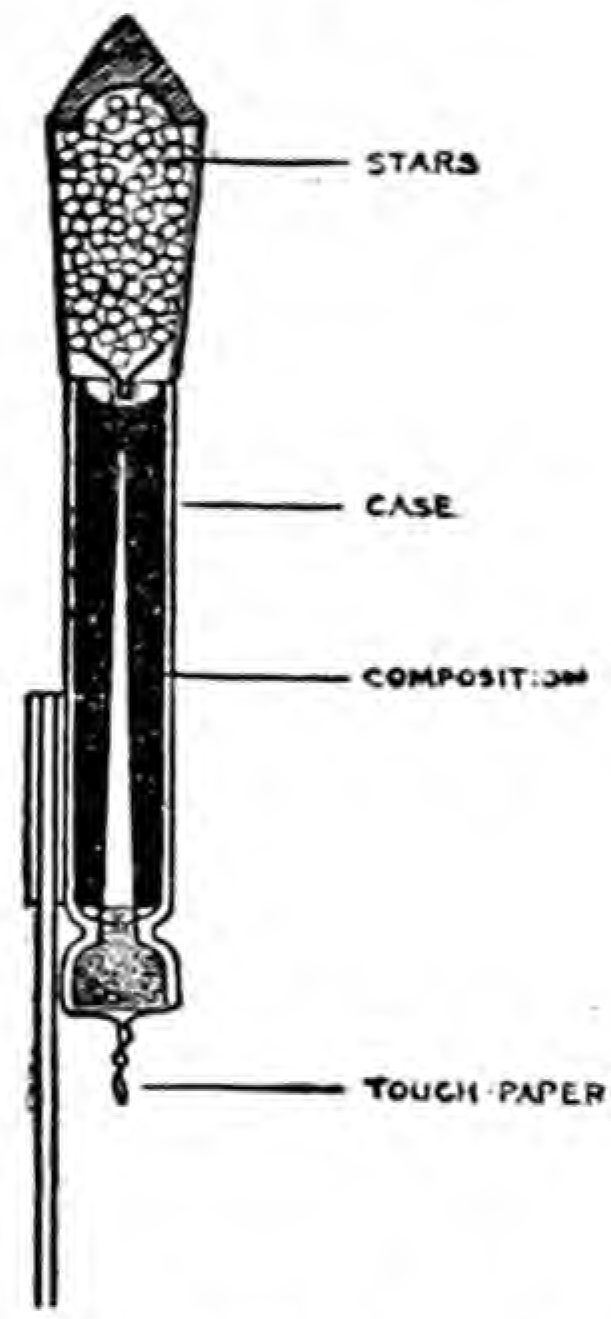


FIG. 3.—*How a rocket is made. The rocket is supposed to be cut in half. When the touch-paper is lit, it sets fire to the composition, and the gases from this drive the rocket into the air. After a short time the material in the front end of the rocket is set on fire, and bursts out in the form of burning stars.*

BREATHING IS A KIND OF BURNING

The reason we can breathe ordinary air is because it has oxygen in it. There is a substance called *phosphorus* which takes fire so readily in air that it is dangerous to handle. It is always kept under water, in case it should catch fire by itself. If you burn some phosphorus in a jar whose open end dips below water, after a time the phosphorus goes out, because there is no oxygen left in the jar. But meanwhile the water rises in the jar. The water rises to take the place of the oxygen that was in the air; this has been joined with the burning phosphorus to make white fumes which soon dissolve in the water. Just about one-fifth of the air is oxygen, and has been used up in burning the phosphorus. The rest of the

air consists mainly of another colourless gas called *nitrogen*. This has nothing to do with burning. If you do the experiment in a bell-jar which is stoppered at the top, you can take the stopper out and quickly put a lighted taper in. You will find it goes out directly; this is because there is no oxygen left in the jar, only nitrogen, and things will not burn in nitrogen. Neither will nitrogen support life. A mouse in a jar full of nitrogen will die almost at once. In a jar of ordinary air, the mouse uses up the oxygen by its breathing, and suffocates only when the oxygen is finished.

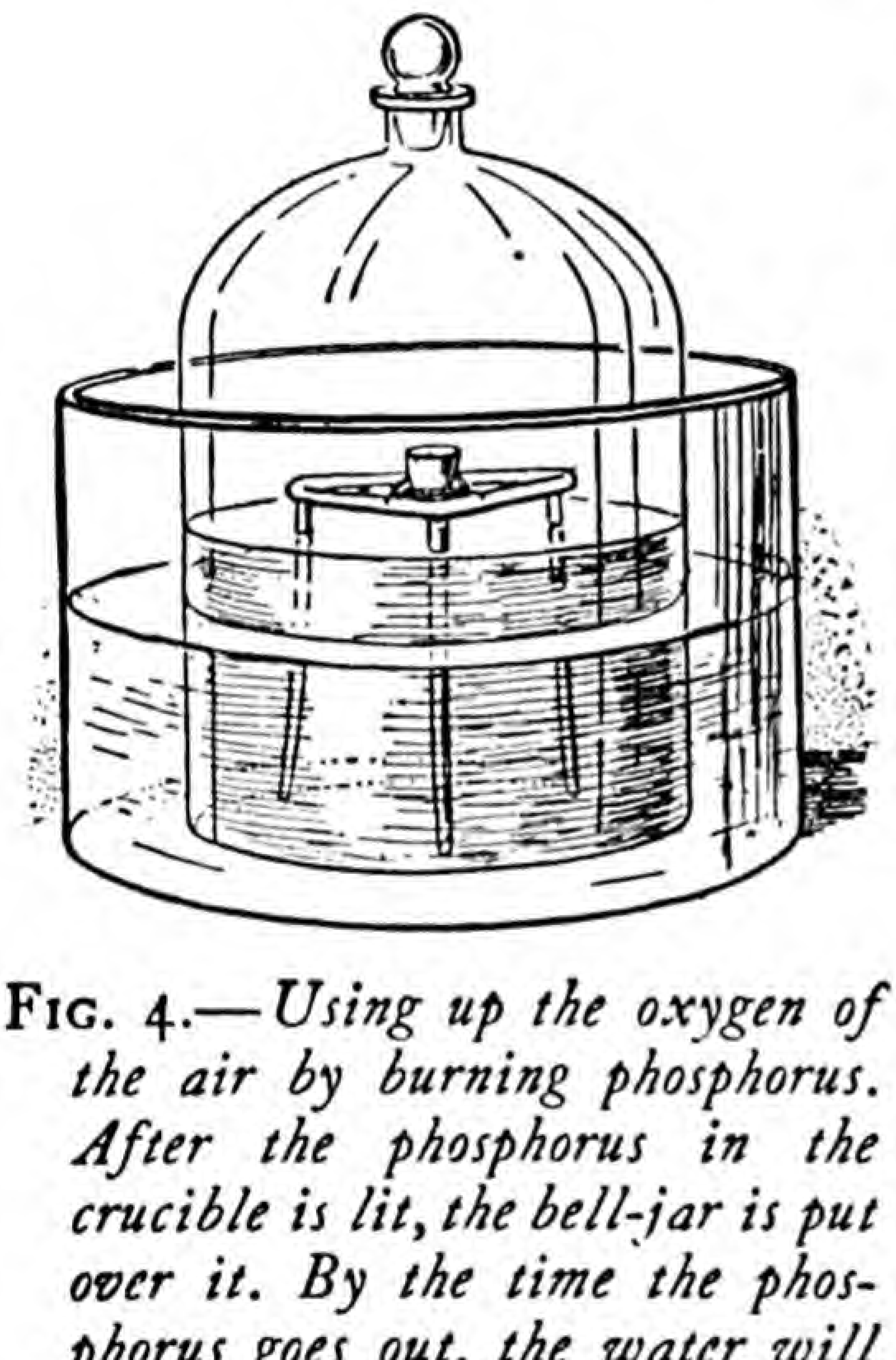


FIG. 4.—*Using up the oxygen of the air by burning phosphorus. After the phosphorus in the crucible is lit, the bell-jar is put over it. By the time the phosphorus goes out, the water will have risen about one-fifth of the way to the top of the bell-jar.*

The fact that a candle needs oxygen if it is to go on burning makes a simple test for oxygen. If a lighted candle or taper goes out when it is put into a hole or cave where there is no wind, then there is no oxygen there, or so little as to be no use for breathing. Sometimes the air in wells, or old mines which are not ventilated, has no oxygen in it. If a man wants to go down into such a place, he first of all lets down a lantern. If the lantern goes on burning, there is enough oxygen for him to breathe; but if it goes out, he knows that it is unsafe for him there.

The fact that oxygen is used up in burning also explains why a good draught helps a fire to burn properly. It is

because the draught brings new air to the fire, and therefore more oxygen is brought to the wood or coal in a given time. A draught of nitrogen would not make the fire burn more quickly: it would put it out. When you close the damper on a stove, you are shutting off some of the supply of oxygen; when you open it, you are letting more oxygen get to the fuel. Some engines have a forced draught, which means that a current of air at high pressure is blown through the furnace. The fuel can burn much more quickly when it has this large supply of oxygen, and so the furnace is hotter.

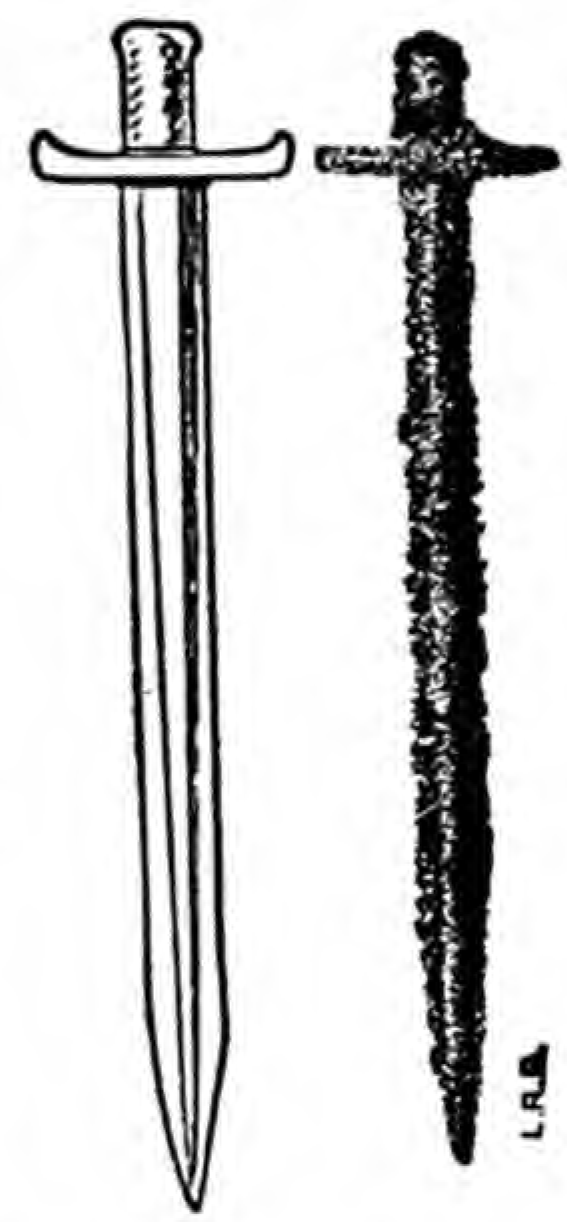


FIG. 5.—*Rusting. A Roman iron sword, found after being nearly 2,000 years in the Thames. Originally it was like the sword on the left.*

Matches and candles glowing brighter and burning faster than usual: here we found our clue as to what oxygen does. Oxygen is the stuff that makes things burn. Animals suffocating if they do not get oxygen: here we are getting a clue about life. It looks as if there must be a kind of slow burning taking place inside living bodies if they are to go on being alive.

All burning is the joining of oxygen with some other kind of stuff. And even with things which are not alive you may get oxygen joining with them so slowly that there is no flame and very little heat. Rusting and tarnishing, for instance, are a sign of this very slow "burning." Ordinary iron rust is simply pure iron combined with oxygen. Thus the only important difference between ordinary burning on the one hand, and on the other hand

rusting or what the oxygen we breathe does in our bodies, is that one is going fast, the other slowly. In ordinary burning, the stuff which is burnt joins with the oxygen very quickly, and great heat is produced. When oxygen joins with the stuff of our bodies, it does so much more slowly, and there is no flame; but all the same, enough heat is produced to keep our bodies warm, even on a cold day. And even when iron rusts, a little heat is produced; but so slowly that it all leaks away before it can warm up the iron. On the other hand, when burning goes on much more quickly than in an ordinary flame, we call it an explosion; this happens, for instance, in the very quick burning of petrol vapour in the cylinder of a motor-bicycle or motor-car.

The air we breathe out is different from the air we breathe in. For one thing (except when the weather is very hot) it is warmer. On a winter's day when our fingers are cold and numb, we can use the heat of our breath to warm them up. For another thing (except in very warm and steamy places) it is wetter. You can show this by breathing on to something cold and bright like a mirror or a spoon. It will go cloudy, owing to the water vapour in your breath condensing into tiny drops of liquid water. If you breathe into a flask which is packed round with ice, you can collect the water which condenses in this way. You must breathe in air from outside the flask through your nose, and then breathe out into the flask through your mouth. In half an hour there will be a spoonful or so of water in the flask (a number of you will have to take turns, for one person would get too tired).

Then, if the oxygen we take in when we breathe is used for a kind of slow burning, there will be less oxygen in the air we breathe out. By making proper measurements

it can be found that the air we breathe out has only about four-fifths as much oxygen as ordinary air.

Finally, the air we breathe out has much more carbon dioxide in it. In Part I we saw that lime-water turned milky when carbon dioxide from soda-water was bubbled through it. You have only to blow through a tube into lime-water for it to go milky, which shows that there is carbon dioxide in the air you breathe out. Ordinary air has a little carbon dioxide in it, but not enough to turn lime-water milky if, for instance, the air is bubbled through the water by the help of a bicycle pump.

At country fairs, men used to play a trick with lime-water to sell "cures for bad breath." They used to say that most people had dirty lungs and bad breath, and that they would prove it. They then called up people in the crowd and persuaded them to breathe into water. But the water was really lime-water. When it went cloudy, they would say: "Look at all the stuff you have breathed out of your lungs; you must be quite rotten inside!" Then if the man bought the "cure" and took a dose, they would get him to breathe into water again. But this time they took care that it was real water, and of course this did not go cloudy, so they could say: "You see, your breath is now clean and good as the result of taking my cure."

Carbon dioxide is made of carbon joined with oxygen. In the slow burning which goes on inside us, some of the oxygen we breathe in is joined up with carbon out of our food to make carbon dioxide. That is the reason there is less oxygen and more carbon dioxide in the air we breathe out.

It is interesting that very much the same thing happens when a candle burns in a closed space. The candle gets shorter, and the air loses some of its oxygen. But the air becomes hotter, and it gets richer in carbon dioxide, and

also in water vapour. So the grease of the candle and the oxygen of the air have not disappeared into nothing: they have joined up to make new kinds of things—water vapour and carbon dioxide. We saw in Part I that soot is formed when something cold is put in a candle flame. When this is done, the heat is not great enough to burn up all the carbon of the grease vapour which is in the flame; and some of it settles out as the tiny black particles of pure carbon that make soot.

Chemical Change

There is one very important fact which burning shows us. It shows us that though things may change their looks or their qualities, or may appear and disappear, the stuff or matter of which the things are made remains the same. Things disappear, as when a candle is burnt; or appear, as when rust appears on a piece of iron; or change, as when magnesium ribbon is burnt and turns into a grey, powdery ash. But the matter of which they are made does not change in amount. It changes in appearance, and joins up in new ways: that is all. The weight of the matter stays the same.

Fig. 6.—*Burning a piece of magnesium ribbon. The burning produces heat, a brilliant light, and some grey ash.*

This you can show with a piece of the metal called magnesium, which is usually sold in the form of a strip or ribbon. Photographers used to employ this ribbon for taking pictures indoors; they still use magnesium for this purpose, but usually in the form of a powder. If you hold a piece of magnesium ribbon in a pair of tongs and light it, a brilliant white flame will shoot up, and the metal ribbon burns away to a grey, powdery ash. In order to get accurate weighings, put a piece of magnesium ribbon in a little porcelain crucible with a lid and weigh it. Then strongly heat the crucible, with its lid on, over a bunsen burner, so that the magnesium burns inside it and turns into ash; let it cool, and weigh again. You will find that the grey powder, instead of weighing less than the original bit of metal ribbon, weighs more. The reason is that, instead of being just pure magnesium, it is magnesium joined with oxygen out of the air: we call it magnesium oxide.

FIG. 7.—*Burning magnesium ribbon in a crucible. If it is strongly heated, the metal magnesium joins with the oxygen of the air to make a grey powder, magnesium oxide.*

So burning is an example of what in Book I we called a chemical change, in which things join with each other (or are just split up) to make new kinds of things. In a chemical change different kinds of matter, joined together in one way in the old substances, become joined together in another way so as to make new substances. Burning is only one kind of chemical change; we saw others in Book I, as when carbon dioxide gas was produced from acid and marble. And a very

important set of chemical changes for us are those which go on when our food gets mixed with our digestive juices.

There are other kinds of changes, some of them just as surprising in their way, which do not mean any new arrangements of matter. When liquid water is boiled and goes off into the air as steam, it is still the same kind of matter—just water, only in a different condition. Or when you turn on the electric light and the filament in the bulb glows and gives out light, it has not changed into a different stuff; it has simply got so hot that it glows, as the tip of a poker glows when you leave it in the fire. Changes like this, when matter alters its condition but not its arrangement, are called physical changes, as opposed to chemical changes, when new kinds of things are brought into being.

There is another fact about burning which we have already touched on in Book I (p. 95), but it is so important that it is worth mentioning again. Burning does not only change one thing into another: it also sets *energy* free. The energy is in the shape of heat; and perhaps you will say that this is all very obvious—everyone knows that burning gives out heat. But really this is just one example of a universal rule—that no change, chemical or physical, takes place without there being an accompanying change of energy.

As we shall see in a later chapter, when liquid water turns into ice (a physical change), energy is given out in the form of heat; while heat has to be absorbed if ice is to be turned into water. The chemical change of splitting water into hydrogen and oxygen can be made to happen only by using energy in the shape of electricity; while, on the other hand, when hydrogen joins with oxygen to

produce water, as in a burning hydrogen flame, energy is set free as heat. The changes which happen when we mix sulphuric acid with water, or pour water on quicklime, result in a great deal of heat being set free. When we see a manure-heap or a wet hayrick steaming, this is because of a particular kind of chemical change going on inside it which is producing heat.

When grass grows, it is making new grass-stuff. As we shall see later (Chapter VI), it makes the new material out of the carbon dioxide in the air, the water in the soil, and a few simple chemical substances dissolved in the water. But to do this it needs to use a great deal of energy: and this energy it gets not in the form of heat or of electricity, but of light. It makes use of light-energy coming from the sun. Later, if the grass is eaten by a cow, the stuff of which it is made is eventually combined with oxygen in the cow's body. This slow burning is accompanied by a setting free of energy; most of this is either in the form of heat, and serves to keep the animal warmer than the air around; or else in the form of energy of movement, so that the cow does mechanical work (p. 58, Book I) in moving itself about. Changes cannot happen to matter without energy being either absorbed or given out in the process.

Burning and Energy

We will take one familiar example of the use which can be made of the energy given off in a chemical change like burning, and then return to where we started and look at breathing again. The example is the engine of a motor-car (or of a motor-cycle: they both work the same way).

First, however, let us go back for a moment to candles

and gas-stoves: they will help to make things clearer. In Book I we already got to know that the brightness of a candle flame was due to tiny particles of unburnt soot (which is just carbon) glowing because they are hot. What is actually burning in the candle flame is the vapour of the candle: the heat turns the wax into wax vapour just as it turns water into water vapour. You can show this by putting one end of a bent glass tube close to the wick of a burning candle, as in the picture. The wax vapour comes through the tube and you can set light to it; it burns there just as well as close to the wick.

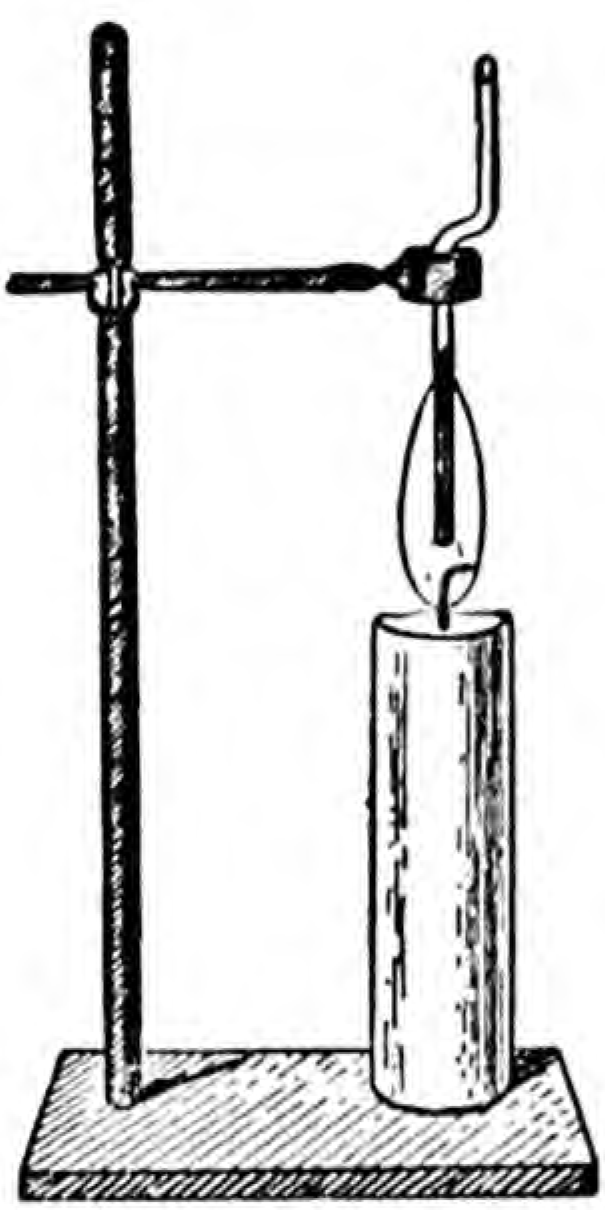


FIG. 8.—*What burns in a candle flame is wax vapour. The vapour can be led off through a glass tube and lit at the other end.*

In an ordinary candle flame there is not enough air mixed with the wax vapour to burn all of it: and so some of the carbon escapes unburnt as soot. That is all right for a candle, because we want a candle to give light, not heat. But if we want the hottest possible flame, we must mix more air with the vapour or gas we are burning. We saw in Book I how in a bunsen burner a bright smoky flame could be turned into a much hotter pale flame, without smoke, by letting air into the flame from below.

The power for driving a motor-car is got by burning petrol vapour. The carburettor of a car is an arrangement for turning the liquid petrol into vapour and then mixing it with the air. When the pistons in the cylinders of the engine move down, they suck a jet of liquid petrol out of the first part of the carburettor, where the float is. Things

are so arranged that this fine jet sprays out and squirts against the side of a tube, and so is converted into tiny droplets which quickly turn into vapour. Petrol turns into vapour at ordinary temperatures much more easily than water: that is why it is dangerous to clean clothes with petrol in a room where a flame, like that of a gas-stove, is burning. Petrol vapour quickly gets into the air, and if there is enough of it, it will catch fire, and there will be an explosion. A hole in the tube from the carburettor to the cylinder lets in air. The mixture of air and petrol vapour gets drawn into the cylinders, and then, after being compressed by the piston as it moves up, is exploded by the electric spark from the sparking plug. The explosion is simply a very rapid burning. It forms new gases and, what is more important, heats them up enormously. We saw in Chapter V of Book I that gases expand when they are heated. The expansion of the heated gases in the cylinder is so sudden and so big that it is what we call an explosion. The series of explosions is what you hear when the engine is running.

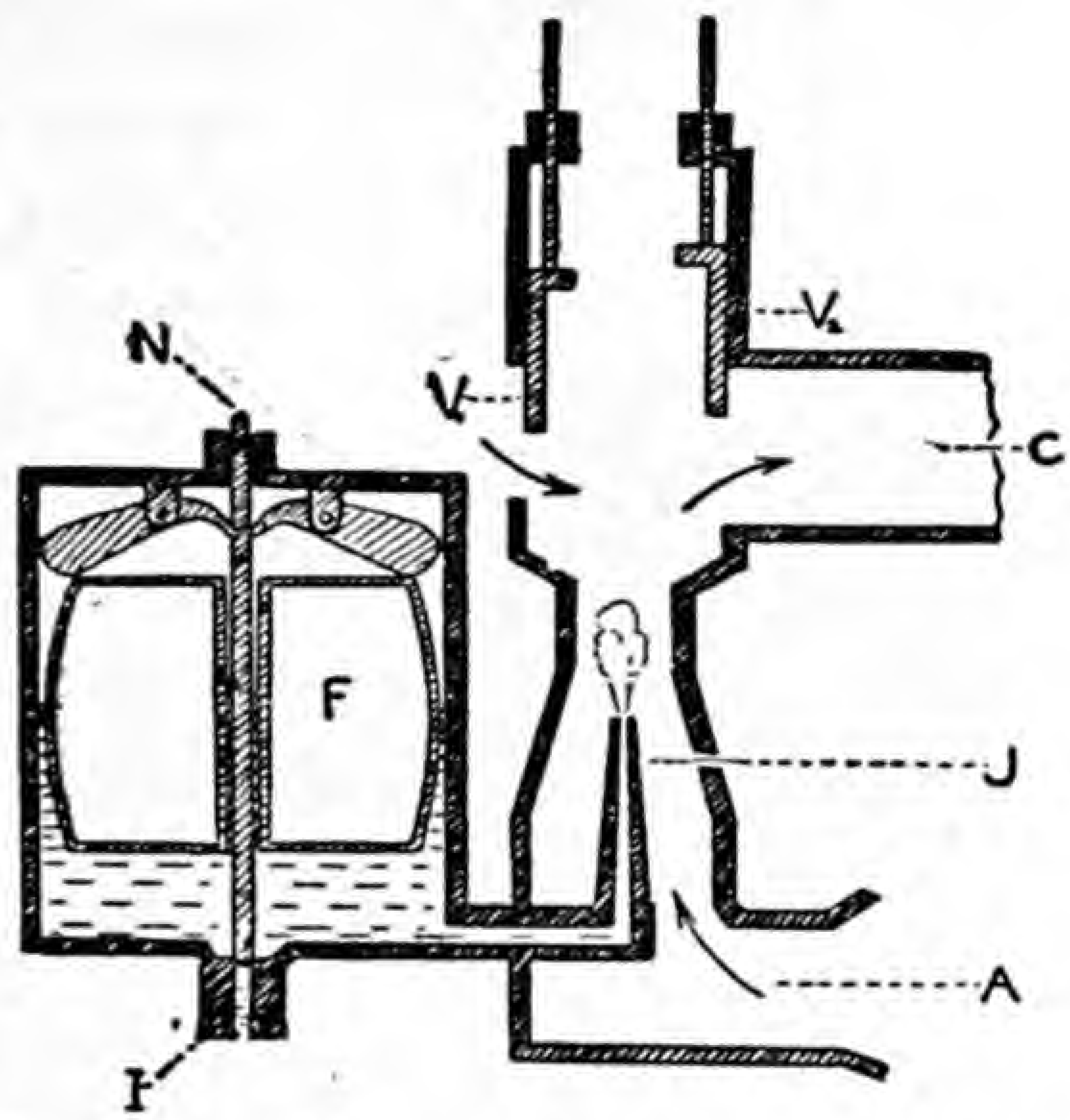


FIG. 9.—*How a carburettor works. The petrol comes into the carburettor at I. It buoys up the float F, which presses on the levers joined to the needle-valve N, so as to press it down and prevent more petrol coming in. The petrol vapour comes out at the jet J and is mixed with the air coming in at A. The valve V_1 lets in or shuts out extra air, while V_2 is the throttle allowing more or less of the mixture to go into the cylinder at C.*

The engine is so arranged that the expanding gases push violently on the head of the piston and bang it down. If too much air is let in, the mixture is "weak" and will not drive the car so well. If, on the other hand, there were no air, the spark could not explode the petrol vapour at all, as there would be no oxygen to join up with it. If too little air is let in, the mixture is too "rich" and some of the petrol vapour is not burnt up, but remains, just as in the candle flame, in the form of soot or carbon, which accumulates and clogs the cylinders: after a time you must have your engine decarbonised.

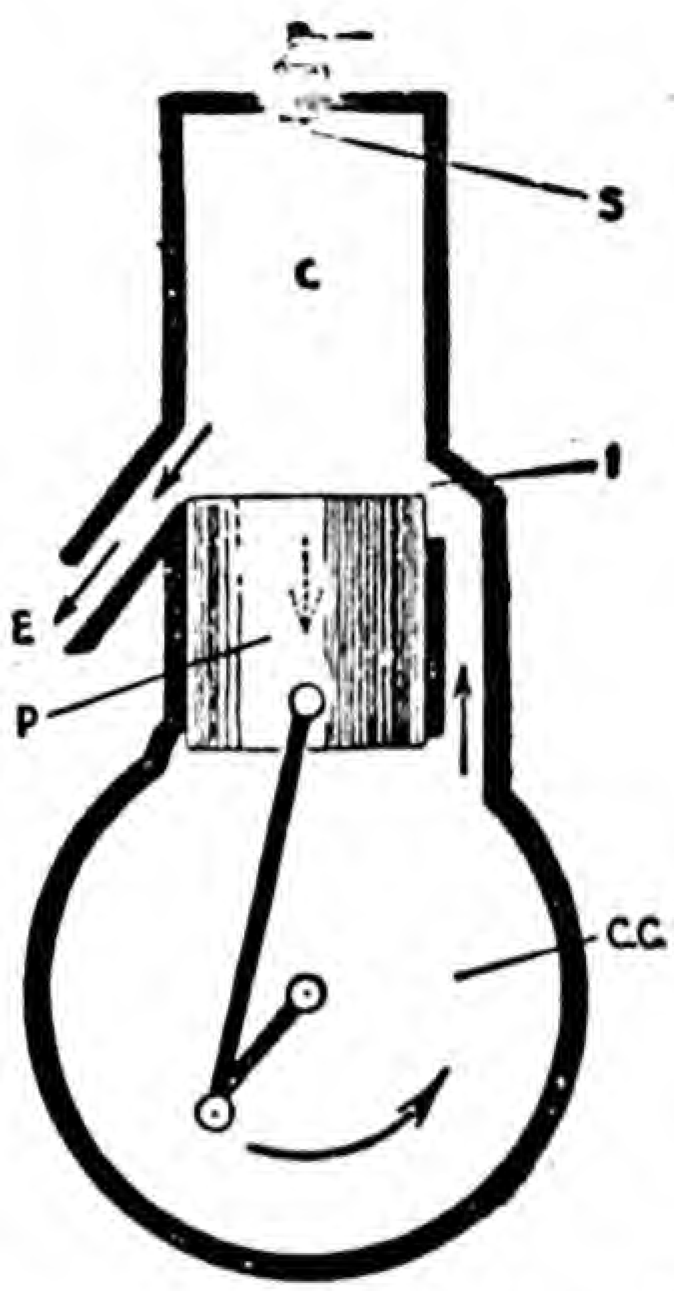


FIG. 10.—*How the cylinder of a two-stroke engine works. The piston P works up and down in the cylinder C. The mixture of petrol and air comes from the carburettor to the crankcase CC, and enters the cylinder at I. When the piston is at the top of its stroke, the compressed gases are exploded by a spark from the sparking plug at S, and the piston is driven down. The waste gases rush out at the exhaust E, which is uncovered by the piston during its downstroke.*

The higher we go, the thinner the air is, as we saw in Chapter V of Book I. So in a given volume of air there is less of the stuff that makes air—less nitrogen and less oxygen. And so high up on a mountain more air has to be taken into the engine to give enough oxygen to explode the petrol properly. In fact, engines for aeroplanes which are meant to fly at great heights must have special arrangements for dealing with this thin air. They are fitted with special high-speed pumps which compress the air that is used to burn the petrol vapour. Even at 12,000 feet, the air supplied to the

cylinders by these pumps is at the same pressure as ordinary air at ground-level. This means that each stroke of the piston sucks in rather more than one and a half times as much oxygen as it would if there were no pumps, for the pressure at 12,000 feet is a little less than two-thirds of what it is at ground-level.

In the same way, breathing gets very difficult at great heights. You find yourself panting and puffing, because you have to take more breaths to get the same amount of oxygen into your lungs. Near the top of the highest mountains, like Everest, the air is so thin that climbers have to rest and pant every few steps. The pressure at 29,000 feet, the height of Mount Everest, is scarcely a third of the pressure at sea-level. That means that you have to take three breaths to get the amount of oxygen you could get in one breath down near the coast. On the Everest Expedition they tried to get over this difficulty by carrying on their backs metal cases with compressed oxygen inside, and breathing the oxygen through a tube. But the trouble was that the extra weight was so great

FIG. 11.—*Mountain climbers with oxygen apparatus. Each man carries six cylinders of compressed oxygen; two thermos flasks* (*p.* 126) *for hot drinks fit between the cylinders.*

that the easier breathing due to the oxygen hardly made up for the labour of carrying it.

We seem to have got a long way away from breathing: and yet not so far as it appears. For just as the main thing about all burning is the mixture of oxygen with the thing to be burnt, so the main thing about breathing is the supply of oxygen from the air to the living matter inside the body. The slow burning which goes on in the body eventually produces, among other things, carbon dioxide gas, and as well as taking in oxygen, breathing has to get rid of carbon dioxide, just as in a motor-cycle the waste gases produced by burning have to be led away through the exhaust pipe.

Different Ways of Breathing

Many animals which live on land breathe oxygen direct from the air: they just take it in through their moist skins. For instance, ordinary earthworms do this; they have no lungs. We, and most familiar animals like mice or cats or birds, take air through the mouth into the special air-bags we call lungs. The skin of such animals is tough and dry and no oxygen can get through it. Insects have a network of tiny tubes all through their bodies, opening by a row of small holes along their sides. You can see the holes easily in a cockroach or a big grasshopper, or in insect-grubs like caterpillars or meal-

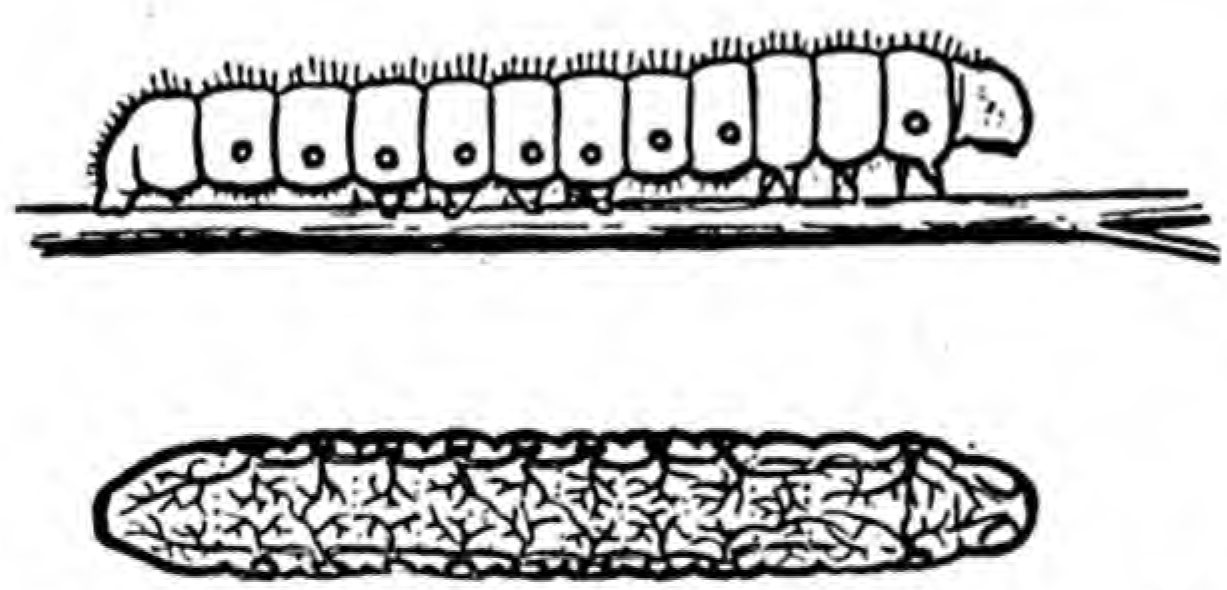


FIG. 12.—*How insects breathe. The caterpillar has nine pairs of little air-holes on the side of its body. These lead into a system of branching air-tubes (shown below).*

worms. The animal expands and contracts its body so as to pump air in and out at these holes; it is very easy to see the quick breathing movements of the body in a wasp. In most cases the holes can be shut by muscles; and by having the sets of holes in the front of the body open when those in the back part are shut, and *vice versa*, a steady current of air is made to run through the system. The air penetrates everywhere along the little tubes, which are easy to see under a microscope. Snails have a hole on the right side just below the lip of their shell, and this leads into a hollow bag which acts as a very simple lung; you can see the hole opening and shutting as the animal takes air into the bag and squeezes it out again. Frogs have lungs and use them, but they also use their skins to breathe with, and as a matter of fact breathe almost as much with their skins as they do with their lungs; while some newts have no lungs and have to rely entirely on their skins, just as worms do.

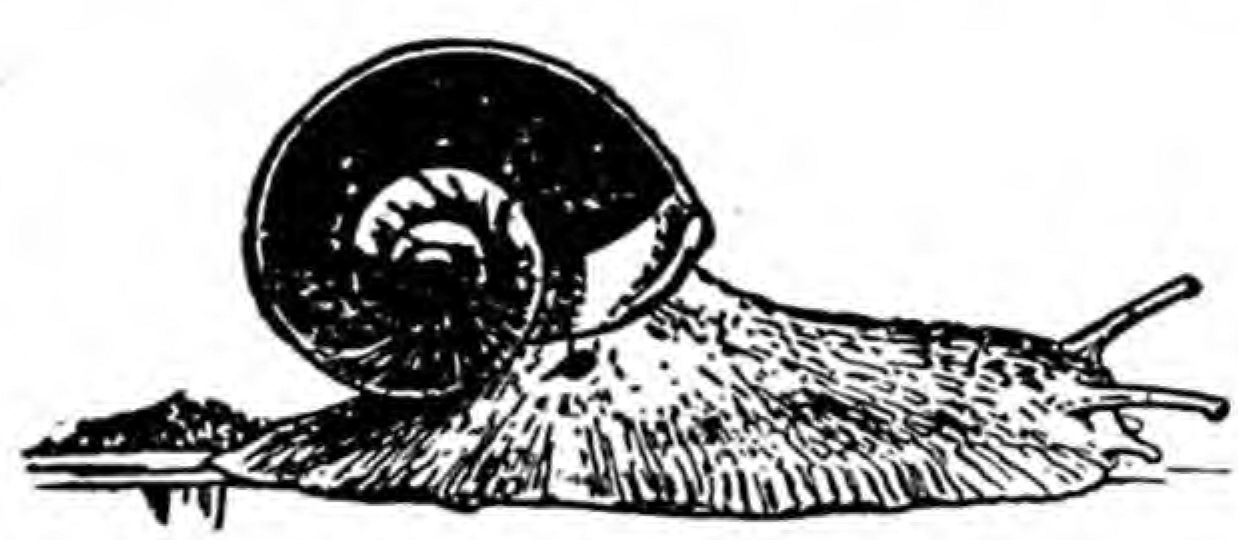


FIG. 13.—*Snails breathe through a hole on the right side of the body. This leads into a lung inside the body.*

But what about animals which live in the water? They have to get their oxygen in a different way. If a gas is in contact with a liquid, some of it dissolves in the liquid; in Chapter VI of Book I we saw how ordinary tap-water has air dissolved in it. Water animals have to rely on the oxygen which has been taken up from the air by the water. Some of them simply breathe this dissolved oxygen through their skins. Leeches, for instance, the blood-sucking wormlike pond animals that doctors once used

for blood-letting, do this, and so do jelly-fish. But most of them have special feathery or flaplike outgrowths, covered with very thin skin through which it is easy to absorb the oxygen; we call these outgrowths *gills*. You can see them below the hind part of the body in the grubs of mayflies, and sticking out on either side of the neck in quite young tadpoles. Later on a flap grows over the tadpole's gills, just as it does over the red feathery gills of most fishes.

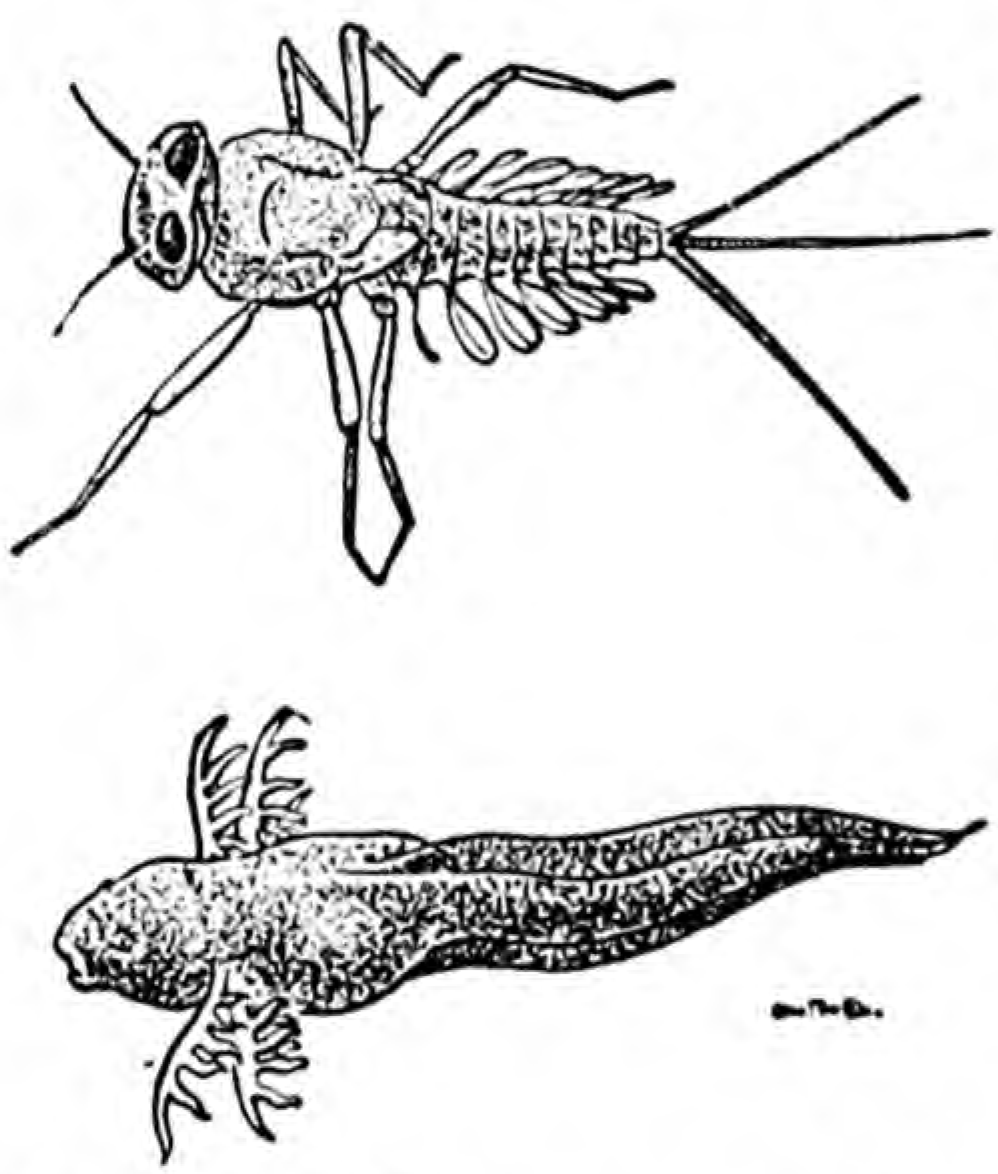


FIG. 14.—*Two water animals with gills (magnified). Above, the grub of a mayfly: it has gills on the hind part of its body. Below, a young tadpole, with its gills on the sides of its neck.*

Both lungs and gills are arrangements for soaking up oxygen into the body and letting carbon dioxide leak out of it; but they are made differently, so that gills will only do this when they are surrounded with water, and lungs only when they have air in them.

The chief reason why a fish dies out of water is that its gills are no longer supported by the water, and all collapse into one sodden mass, so that oxygen cannot get to most parts of them. If their feathery branches could still stand out as they do in water, and if they could be kept moist in the air, the fish could go on breathing. As a matter of fact, there are some fishes that can breathe out of water for quite a long time, by having their gills and gill-covers made in a special way. The mudhopper fish, for instance, skips gaily over the mudflats of tropical marshes, and even

climbs up the roots of the mangrove trees that grow there.

If a man wants to breathe under water, he has to take air down with him, or have it pumped to him. With the diving outfits generally used, air is pumped down through a pipe from a ship. In a submarine or a diving-bell, air is taken down. This happens, too, with some new types of diving suits, in which oxygen cylinders are carried, and the carbon dioxide produced by breathing is got rid of by means of chemicals. As a matter of fact, there are some animals which do the same kind of thing. Some water-beetles come up to the surface, entangle bubbles of air in a special fringe of hairs on their bodies, and breathe this under the water after they have dived. And the water-spider, as well as doing this, actually takes bubbles of air down and fills its silk nest with them. These animals, of course, cannot stay under water all the time like a fish, but often have to come up to the top of the water and get fresh air.

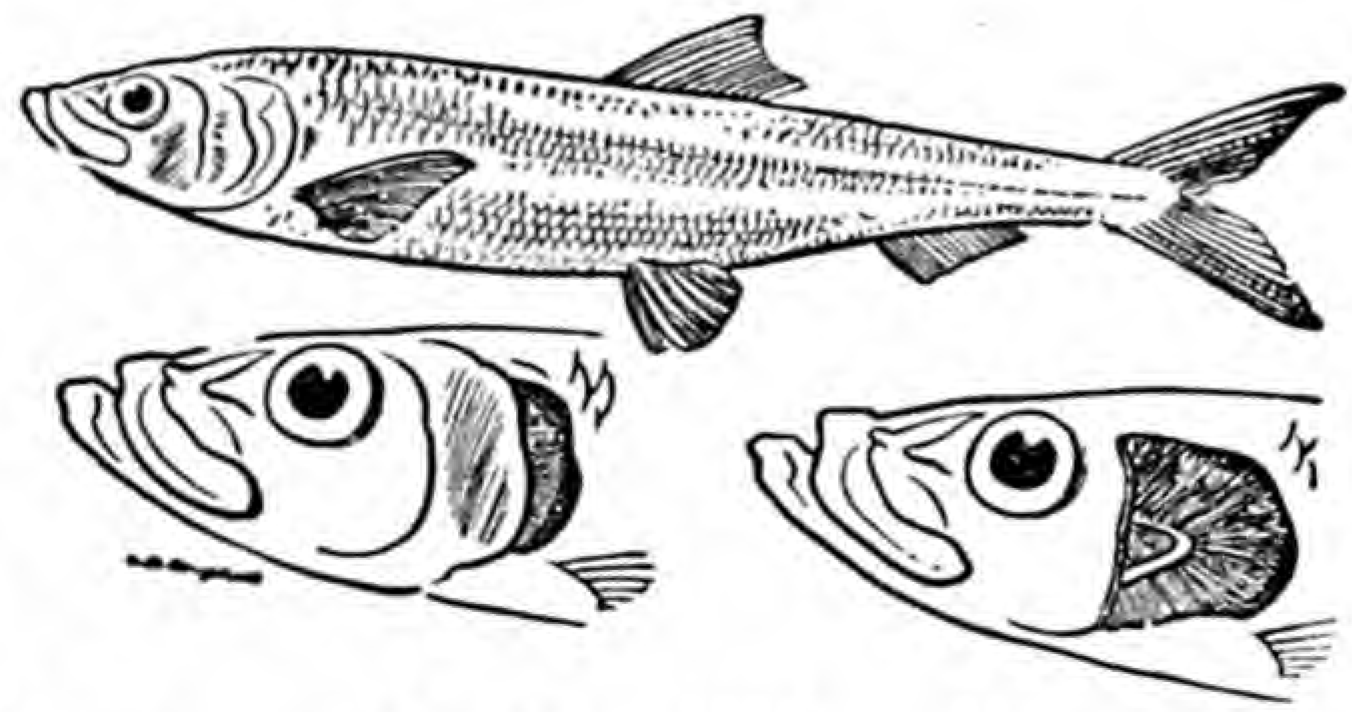


FIG. 15.—*Another gill-breathing animal—the herring. Its gills are covered by a movable flap. When the flap moves out (below, left) the tips of the gills show; but to see them properly you must cut the flap away (below, right).*

If you boil water, the heat drives all the dissolved air out of it, and when it gets cool again, it takes a long time before much air can soak back into it again, and a fish or a tadpole put in water which has been cooled after being thoroughly boiled, will suffocate. In fact, the heat in a

shallow tropical pool or swamp is enough to drive out most of the dissolved oxygen: so the fish which live in such places have a hard time getting oxygen out of the water, and most of them have some special lung-like arrangement as well. Every now and then they come up to the surface and take a gulp of air.

Plants, too, have to breathe quite a lot of oxygen, as you can prove by putting some plants in a stoppered jar in the dark (we shall explain later, in Chapter VI, why they must be in the dark). After they have been there for

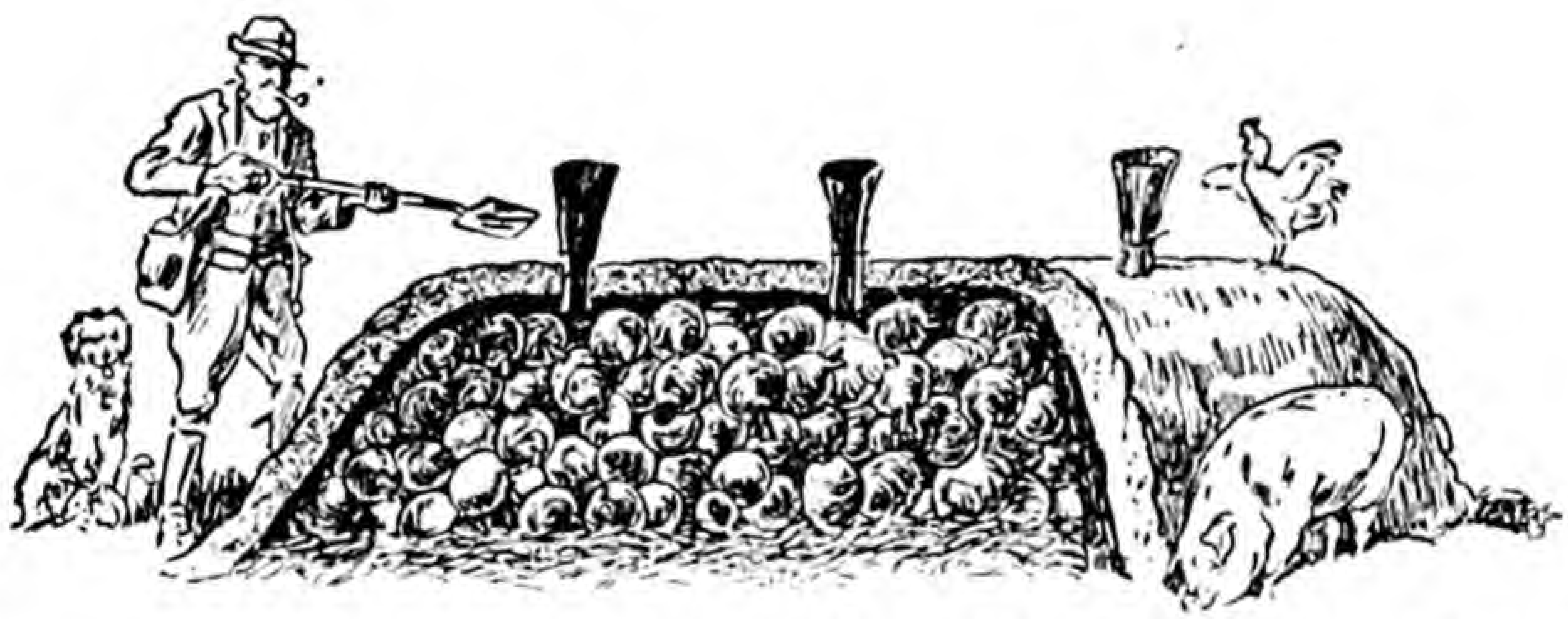


FIG. 16.—*A turnip clamp cut open. It has holes in it to give the turnips air to breathe. The straw tubes in the holes are to prevent too much earth and water falling on to the turnips.*

a day or so, if you open the jar quickly and thrust a lighted taper into it, it will go out. It can no longer burn because the plants have breathed all the oxygen out of the air in the jar. They will only do this when they are alive: if you kill them with boiling water first, they do not breathe.

Potatoes and turnips, when put up for the winter in the mounds of earth which farmers call clamps, have to breathe; so holes are left here and there in the covering of earth to let air in. Apples have to breathe to ripen; and if they breathe, they cannot help ripening. One of the chief

reasons for cold storage on fruit boats is to slow down the breathing of fruit so that it will not get over-ripe. Green leaves breathe; these, however, take in carbon dioxide as food material, as well as oxygen for ordinary breathing purposes, as we shall see later.

Animals and plants, in fact, and human beings too, are slow-combustion engines, while motor-cars and motor-

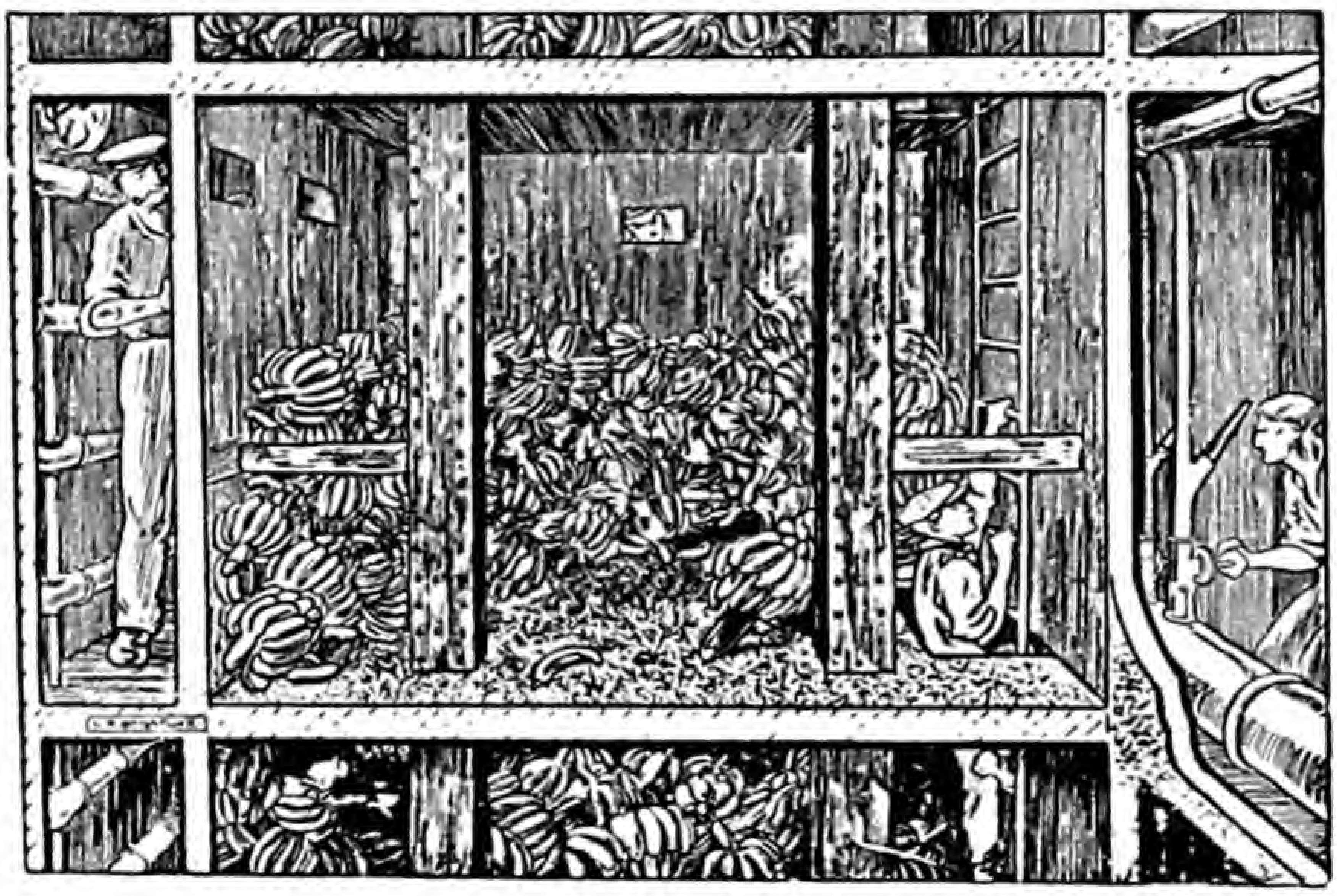


FIG. 17.—*Part of a cold-storage hold on a banana boat. The cold pipes are in the little passage which goes all round the hold. There are thermometers on the pipes (on the right); the man is regulating the flow of cold liquid through the pipes. The little windows are to look in and see if any of the bananas are going bad.*

cycles are quick-combustion engines. The construction of an animal differs in every detail from that of a motor-car. But men and motor-cars are like each other in the one main chemical fact, that they get the energy for the work they have to do from combustion; in both, chemical substances with carbon in them are combined with oxygen from the air to provide the energy that is needed.

Our Bodies are Slow-Combustion Engines

What actually happens in your body is this. Your chest acts as a pump for sucking air into your lungs and squeezing it out again. The air comes down your windpipe; this branches again and again, and the smallest branches end in little air-sacs in your lungs. Most of your lungs consist of these air-sacs, and that is why they look spongy (you can see this for yourself in "lights" in a butcher's shop, which are just the lungs of sheep or cattle). The air-sacs are lined with a moist and very thin skin; and just below this skin are thousands of tiny tubes along which your red blood is slowly flowing. The blood is driven all round the body by the heart, which is nothing but a pump made of muscle. Before getting to the lungs your blood has been all over the rest of your body; and the slow combustion going on in the muscles and other living parts of you has used up some of its dissolved oxygen, but has also given it a lot of carbon dioxide. In fact, the blood in your lungs is short of oxygen, but has extra carbon dioxide in it.

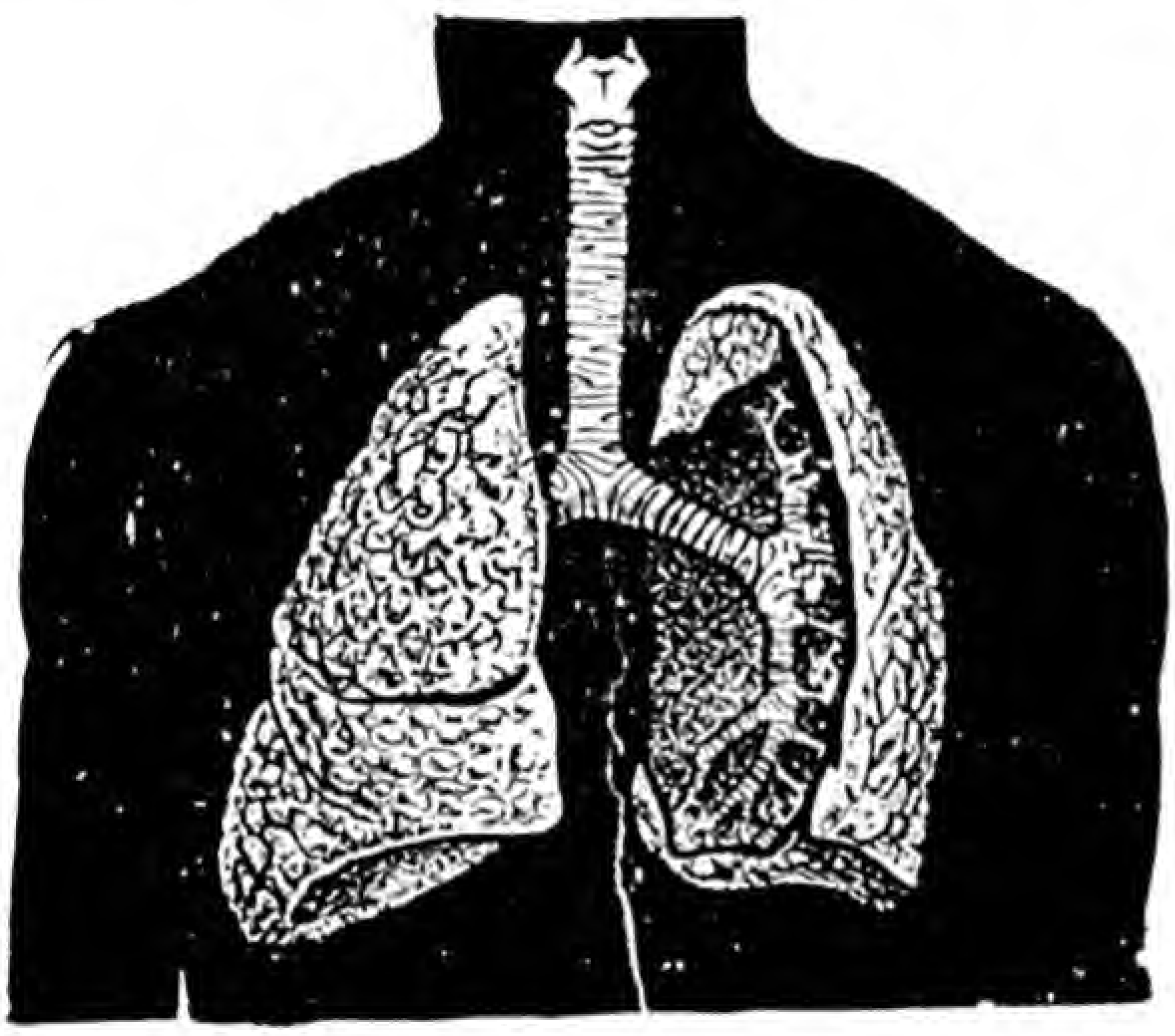


Fig. 18.—*The lungs and windpipe as they lie in the body. The lung on the right is supposed to have been dissected so that you can see how the windpipe branches to reach every part of the lung. The swelling at the top of the windpipe is the voice-box.*

Now while the blood trickles slowly along through the lungs, it is only separated from the air in the air-sacs by

a microscopic thickness—the very thin skin of the air-sacs, and the equally thin wall of the tiny blood-tubes; and gases can easily pass through such thin skins, provided they are moist. So what happens is that, as the blood here is short of oxygen, oxygen leaks into it from the air-sacs; while some of the extra carbon dioxide which is dissolved in the arriving blood leaks out into the air in the air-sacs, and is breathed out by the pumping of your chest. That is why the air you breathe out has less oxygen and more carbon dioxide in it than ordinary air.

But your blood has other things in it besides oxygen and carbon dioxide. In its journey round the body, it passes through the walls of your intestines in tiny tubes just below the surface, in the same way as it does through the walls of the air-sacs in your lungs. And there it takes up dissolved food.

So your blood has in it dissolved oxygen gas which it has got from your lungs, and dissolved foodstuff which it has got from your intestines. And it carries the oxygen and the food all over your body, just as railways and motor-lorries carry the supplies which they get from farms and factories, from docks and harbours, and take them all over the country.

Whenever any part of you *does* anything, it has to use up some energy. It gets the energy it needs by combining oxygen with some chemical substance which serves as fuel; and this fuel is either just dissolved food, or is made from dissolved food. Every time you walk or run, the muscles of your limbs burn fuel; when you talk, the same is happening in your tongue-muscles; slow combustion is going on in your brain when you think, in your stomach when you digest, in your skin when you sweat.

Some slow burning is needed just to keep you alive and warm: your heart-pump and your chest-pump go on working and needing fuel even when you are asleep, and so do many other parts of you.

So all the different parts of your body are all the time taking dissolved food and oxygen out of your blood. (The exact amount will depend on what they need: when you are running, your muscles use much more than when you are sitting still.) But they are also putting other things into the blood. When the slow burning goes on, the fuel combines with the oxygen to make new chemical substances, just as happens when a candle burns. As a matter of fact, the most important of the substances made by the slow burning in your body are the same as those made by the quick burning of the candle—carbon dioxide and water. Besides these, there are other substances which have nitrogen in them.

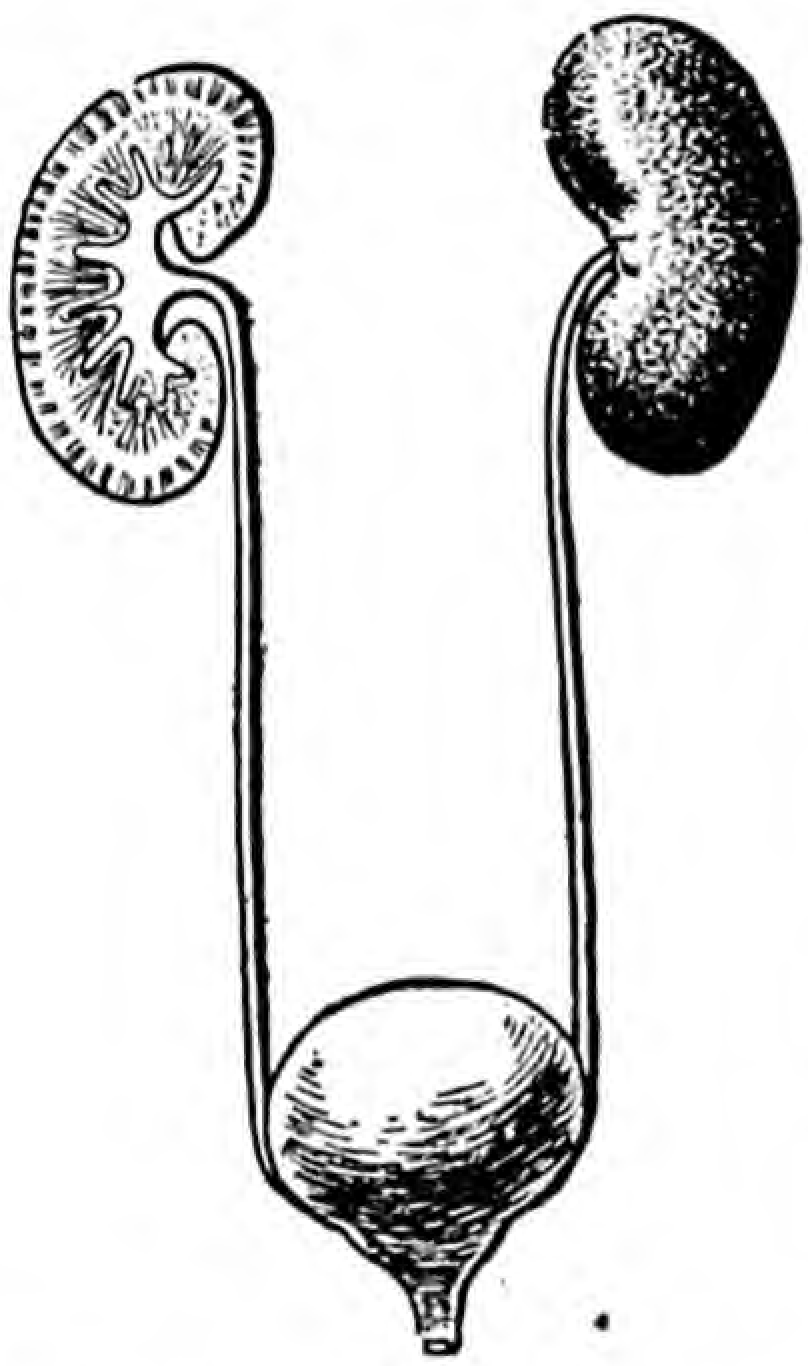


FIG. 19.—*The kidneys and bladder of a man. The kidney on the left has been cut across. It is made of thousands of tiny tubes which drain into the big tube which leads to the bladder.*

These substances have to be got rid of, just as the gases produced in the explosive burning in a motor-car engine have to be got rid of in the exhaust. What happens is this. The blood carries them, of course in a dissolved state, round the body. When it comes to the lungs, it unloads its carbon dioxide and some of its excess water into the air-sacs. When it comes to the skin, it unloads some more of

its excess water, and this is got rid of in the sweat or perspiration, which also contains a little salt. And when it comes to the kidneys, it unloads the rest of its excess water and all the waste substances with nitrogen in them, and these are got rid of from the body in the yellow fluid which we call urine. The solid material or *fæces* which we get rid of from our bowels is waste matter of a different kind. It is food-material which has never been used because it has not been digested.

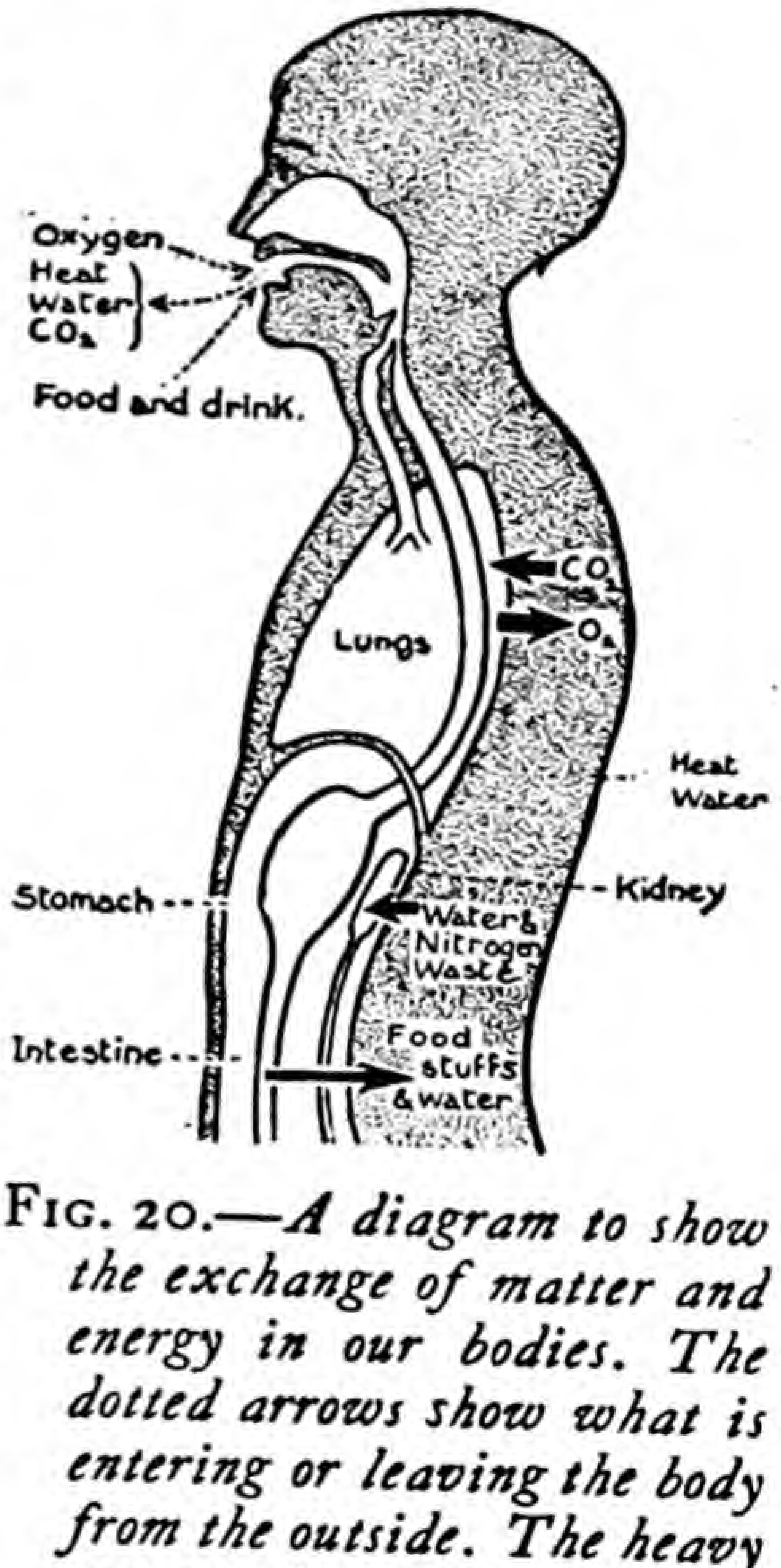


FIG. 20.—*A diagram to show the exchange of matter and energy in our bodies. The dotted arrows show what is entering or leaving the body from the outside. The heavy arrows show what is entering or leaving the blood.*

Besides these new chemical compounds, the slow combustion in our bodies gives rise to energy. Some of this goes in moving us about, and the rest is set free as heat. Some of the heat passes out with our breath and our urine and so forth, but most of it, after serving to keep us nice and warm, just leaks away through our skin. There are wonderful arrangements in our bodies for regulating the amount of heat allowed to leak out, and so for keeping our temperature always the same: we shall speak about these later, in Chapter V.

So the great differences between the combustion that goes on in a motor-car and in our bodies are, first that the combustion is quick in the engine and slow in us, and secondly that in the motor-car everything that is burnt

and all the waste products that are got rid of are dealt with in gas form, while in our bodies everything is dissolved in liquid of some sort or another.

We have skipped about a good deal in this chapter:—from breathing to burning; from burning to chemical change; from this to the use of chemical change for getting energy; from this to the working of a motor-car; and so back from the motor-car to the human body again. But it has all had to do with oxygen and what happens when it combines with other things.

We have seen that we ourselves are made to get energy by slow combustion. But though we are slow-combustion engines, we are many other things too: and in later chapters we shall look at a number of other interesting facts about the way our bodies are constructed and how they work.

CHAPTER II

HOW WE MOVE OUR BODIES

Movement and Muscles—Sinews, Joints, and Bones—Levers—How Muscles Work in the Body—How Different Animals Move

Movement and Muscles

IN the first chapter we learnt something about our bodies. We learnt that they need energy in order to work, and that they get this energy from the joining-up of oxygen with substances that come from our food.

If we had space in this Book, it would be interesting to say more about the food that we have to eat as fuel to drive our body machine and as material to repair it and make it grow. We should want to discover what the chief kinds of food were made of, and how much we needed of each kind. We should want to understand what is meant by digesting our food, and how it got into our blood. Another question would be how and where we stored up reserve supplies of extra food, what we did with the parts of the food we could not use, and how we got rid of the waste materials. We should also have to find out just how the blood was pumped round the body, and why it always circulated in one direction, like one-way traffic.

To understand all this, we should have had to describe a great many different organs; (an organ is a part of the body which has a particular kind of work to do; the heart is an organ for pumping blood, the lungs are organs for breathing). We should have found that our bodies are

not made anyhow, but are full of complicated machinery, all beautifully arranged for doing the work it has to do. We should have seen what a wonderful arrangement of valves there is in the heart-pump. We should have found that coiled up inside a man is thirty feet of tube to help him in digesting his food and getting it into his blood. We should have discovered about glands, which are parts of the body that make special chemical juices for different purposes; the pancreas and the liver, for instance, make juices which help us to digest our food. We should have seen how the kidneys act like a special kind of filter, and how the amount of blood running through a particular set of blood-pipes can be regulated according as to whether that part of the body needs less or more blood.

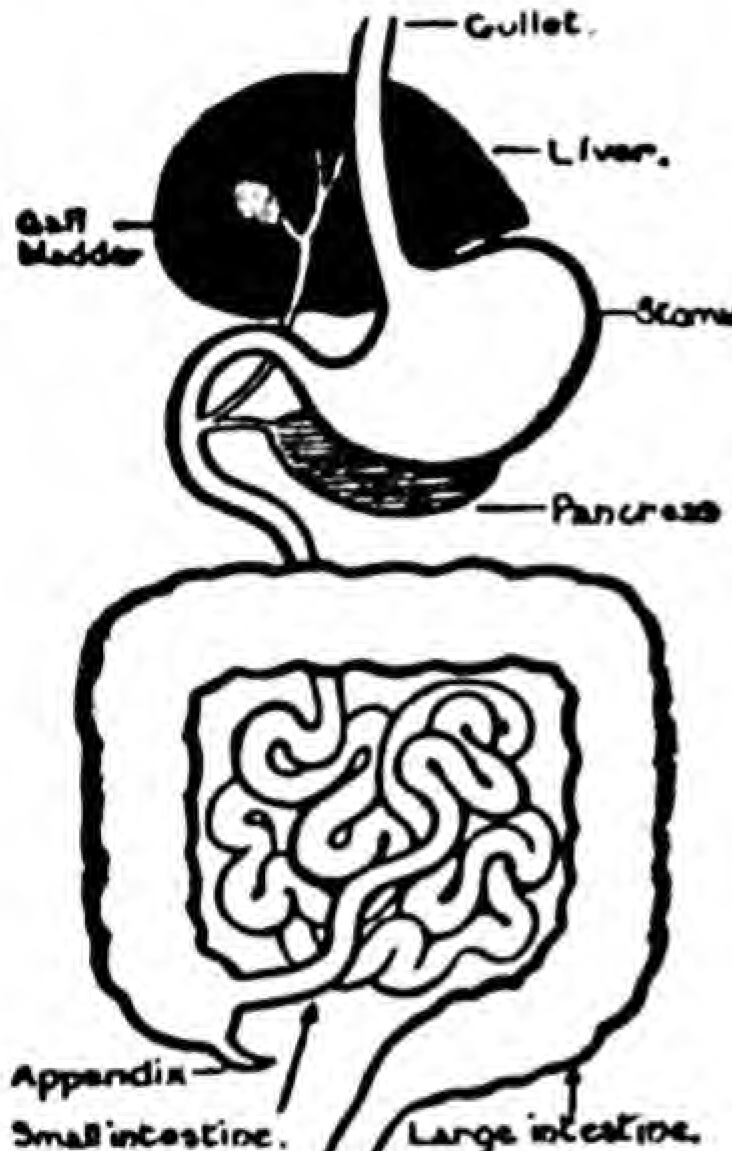


FIG. 21.—*A diagram of a man's digestive system. Most of our digestion is done in the stomach and small intestine, and the digested food is passed into the blood through the wall of the small intestine. The juices of the liver and pancreas are poured into the beginning of the small intestine.*

All this, however, would take a great deal of space. We have not room to do it here, so it must wait to a later Part. In this Part we must skip over all this part of the working of our bodies and come straight to the question, "how does the body use the energy it gets from the slow combustion of the food it eats with the oxygen it breathes?"

We have said that part of the energy appears as heat. We shall talk about what happens to this in Chapters IV and V. The rest is used in making movements, and in

this chapter we shall try to understand some of the machinery by which we move ourselves or parts of ourselves from place to place, or by which things like food or blood are moved about inside ourselves.

An animal has to move about to get its food, as well as to escape, if possible, being used for food by some other animal. As a matter of fact, over half our weight or the weight of familiar animals like dogs or sheep or rats, is taken up by arrangements for moving about.

To move about, we, like animals, need three main kinds of organs. We need organs to generate energy for producing the movement—in other words, for doing mechanical work: these would correspond to the engine of a car, or the legs of a pedal cyclist. We need organs for making sure that the mechanical work shall be turned into the kind of movement which is wanted: these would correspond to the wheels and steering arrangements of a car or a bicycle. And we need arrangements for getting the energy transmitted to where it is wanted in order to produce the movements: these would correspond to the "transmission" in a car, or the pedals and chain in a pedal cycle. In our bodies, the organs that produce the energy for movement are our muscles: the organs which make sure that the movements shall be what is wanted are the bones of our skeleton: and the organs for getting the movement from one to the other are the tendons and sinews and such-like, which are strings or sheets of tough material which join the muscles to the bones.

Muscles are what we usually call flesh or meat. In a joint of meat there will be some fat and some sinew, and a few other things, such as blood-vessels and nerves. But most of it is lean meat, and all the lean meat is just muscle.

We saw how the fuel for our bodies was food dissolved

in our blood. It is in the muscles that most of this body-fuel is used, by being slowly combined with oxygen, and so producing energy. Some of the energy is given out as heat which keeps us warm; and the rest is used in doing mechanical work Book I, p. 58).

The job of a muscle is to *contract.* In Book I we explained how most things contract when they get colder, and expand when they get hotter. But when we say a muscle contracts, the word is not used in quite the same sense as when we say that an iron rail contracts. In the cold, the iron rail actually gets smaller: it shrinks in length, in breadth, and in depth. But when the muscle "contracts" it does not get smaller, but only changes its shape. It shrinks in length, but increases in breadth and depth, like a piece of stretched rubber cord when you let it go. A muscle when it is not contracting is something like a slug that is crawling along, and when it contracts it is something like a slug after you have touched it and it has humped itself up. From being long and thin, it becomes short and fat (Fig. 22).

However, the muscles that move us and the parts of our bodies are not free to crawl about like a slug. At their ends they are joined to bones. So when they contract, they pull on the bones to which they are joined. The bones are freely hinged together in various ways, and so the contraction of the muscles moves the bones.

Let us take a familiar example. Everyone has heard of the biceps muscle: it is the muscle in the front of your upper arm, and "comes up" when you bend your elbow. It is made of a pink mass of thousands of tiny fibres, with plenty of blood-vessels to supply fuel and oxygen. The whole thing is surrounded with a sort of cover of tough membrane. At each end, this cover is continued into a

very strong tough string called a tendon. As a matter of fact, there are two tendons at the top end, and these are fixed to the flat bone at the top of your back which is called your shoulder-blade: the tendon at the bottom end is fixed to the bigger of the two bones which you have in the lower part of your arm.

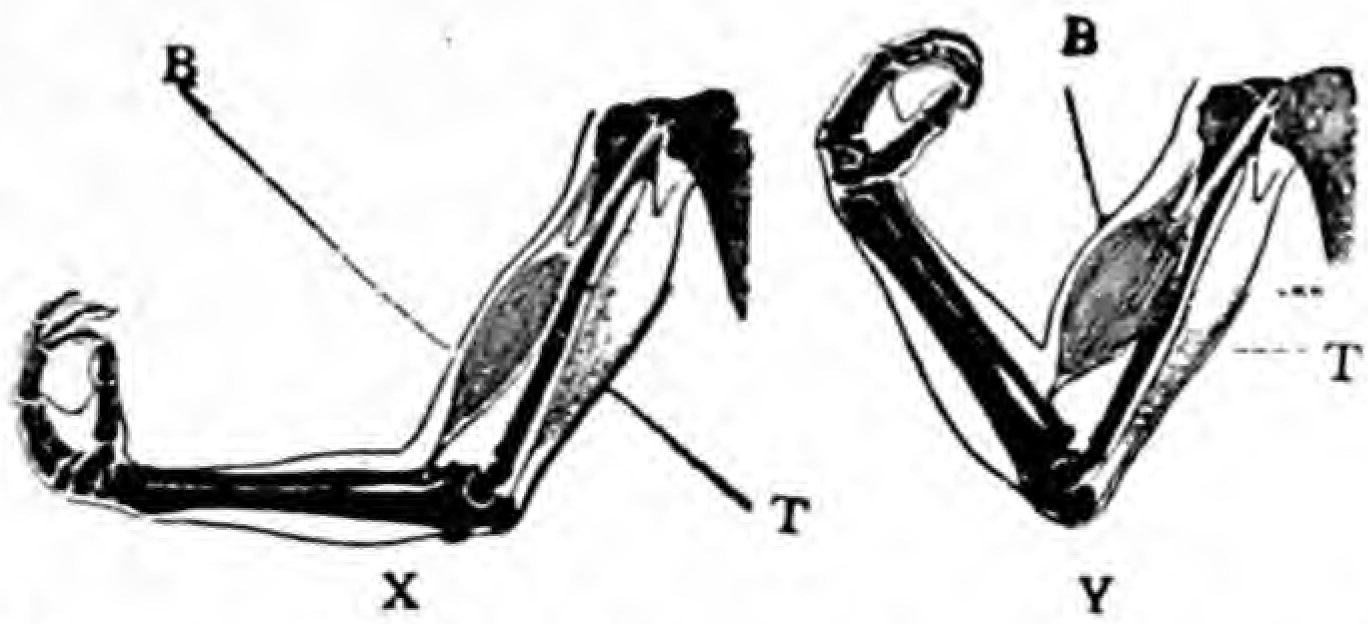


FIG. 22.—*The forearm is a lever, with muscles for moving it in opposite directions. The biceps muscle* (B) *is in front of the upper arm, the triceps* (T) *behind. When the biceps contracts, as in Y, the arm is bent. In X, both biceps and triceps are slightly contracted.*

When the biceps muscle contracts, it gets shorter but at the same time thicker, as you can feel when you bend your arm. That will mean a pull on the tendons at its two ends. The shoulder-blade, to which the top tendons are attached, is fixed in such a way that it cannot move down in the direction of the pull of the tendon: but the bones of the lower arm are joined to the bone of the upper arm by a joint which works like a hinge, and will let them turn in one direction. So when your biceps contracts, the lower part of the arm must bend up.

Or again, if you pass your hand down the big muscle that makes most of the calf of your leg, you will find that it gets narrower, and then you will feel the soft muscle turning into a hard cord, which runs down for a couple of inches and joins on to the extreme hind end of your heel. This hard cord is a big tendon. The tendons at the other end of the calf-muscle are attached to the bottom of your thigh-bone. When the calf-muscle con-

tracts, as it cannot pull your thigh down, it pulls your heel up, and this pushes your toes down. If your toes are on the ground, it just pulls your heel up, and so your whole body is lifted (Fig. 32).

If you cut the skin off a dead frog's leg, you can see its calf-muscle: if you pull on this, the frog's foot will move down, away from the body, just as your foot does when you contract your calf-muscle.

A muscle can pull, but it cannot push. It pulls when it contracts, but when it stops contracting, or *relaxes*, as we call it, it simply gets more limp. So when a muscle has moved a bone in one direction, it cannot move it back again to where it started from. To do that, another muscle is needed, pulling the opposite way.

As an example, let us go back to the arm. Suppose you have used your biceps to bend your arm up, and then you want to straighten your arm again. You cannot do this by relaxing your biceps: there is no push in a limp muscle. What you need is a muscle to pull on the opposite side of the bones of your lower arm. There is a muscle which does this; it is called the triceps. The biceps grows on the front of your upper arm, the triceps on the back of it. The biceps can bend your arm up because its lower end is fixed to the bones of the lower arm on the side away from the projecting tip of your elbow (your "funny-bone"): the lower end of the triceps is joined to the funny-bone itself. The upper end of the triceps, like that of the biceps, is joined to parts of your shoulder which cannot move. So when the triceps contracts, it pulls on your funny-bone; and as this sticks out beyond the elbow-joint, a pull on it straightens out your lower arm. So your triceps and your biceps are both concerned with moving the same part of your body—the lower arm; but one looks after its

movements in one direction, the other looks after its movements in the other direction. When your arm is bent up as far as it can go, the biceps is contracting hard, while the triceps is quite relaxed. When it is perfectly straight, it is the biceps which is relaxed, the triceps which is contracting. And when your arm is partly bent, both the biceps and the triceps must be contracting a certain amount.

Owing to the fact that muscles can only pull but not push, every movement in the body has to be looked after by a pair of muscles like this, one to pull one way, the other to pull it back again. Another example is the foot. We have already seen how your calf-muscle bends your foot down. To move your foot in the opposite direction, you use the muscle which runs up your shin-bone, just outside its front edge. It is easy to feel this muscle bulging and getting hard when you keep your heel on the ground and bring your toes upwards as far as they will go. The shin-muscle is not nearly so big or so powerful as its opposite number the calf-muscle. This is because it does not have to be so strong. When you are walking, the calf-muscle has to lift the whole weight of your body; but the shin-muscle never has to do more than lift your foot.

Even when we are not moving, but standing or sitting still, a great many of our muscles have to be working. When someone goes to sleep in a chair, you have seen how his head falls over forwards and to one side. This is because the muscles in his neck are no longer contracting: we say they are relaxed. You can feel for yourself how the muscles in your throat pull your head forward and down; those at the back of your neck pull it back and up; and those on either side of your neck pull your head towards this side or that. When you are sitting or standing

with your head straight, all four sets of muscles in your neck must be contracting, each just the right amount; they are all pulling against each other, and keep your head balanced so that it does not fall over.

In the same way, if you are to stand up, muscles must be contracting to keep your legs straight, and other muscles must be pulling on your backbone to keep your body from falling forwards or backwards or sideways. The reason a man in a faint falls down is that his muscles, including those needed for balancing him on his legs, are no longer under control, and become relaxed.

Sinews, Joints, and Bones

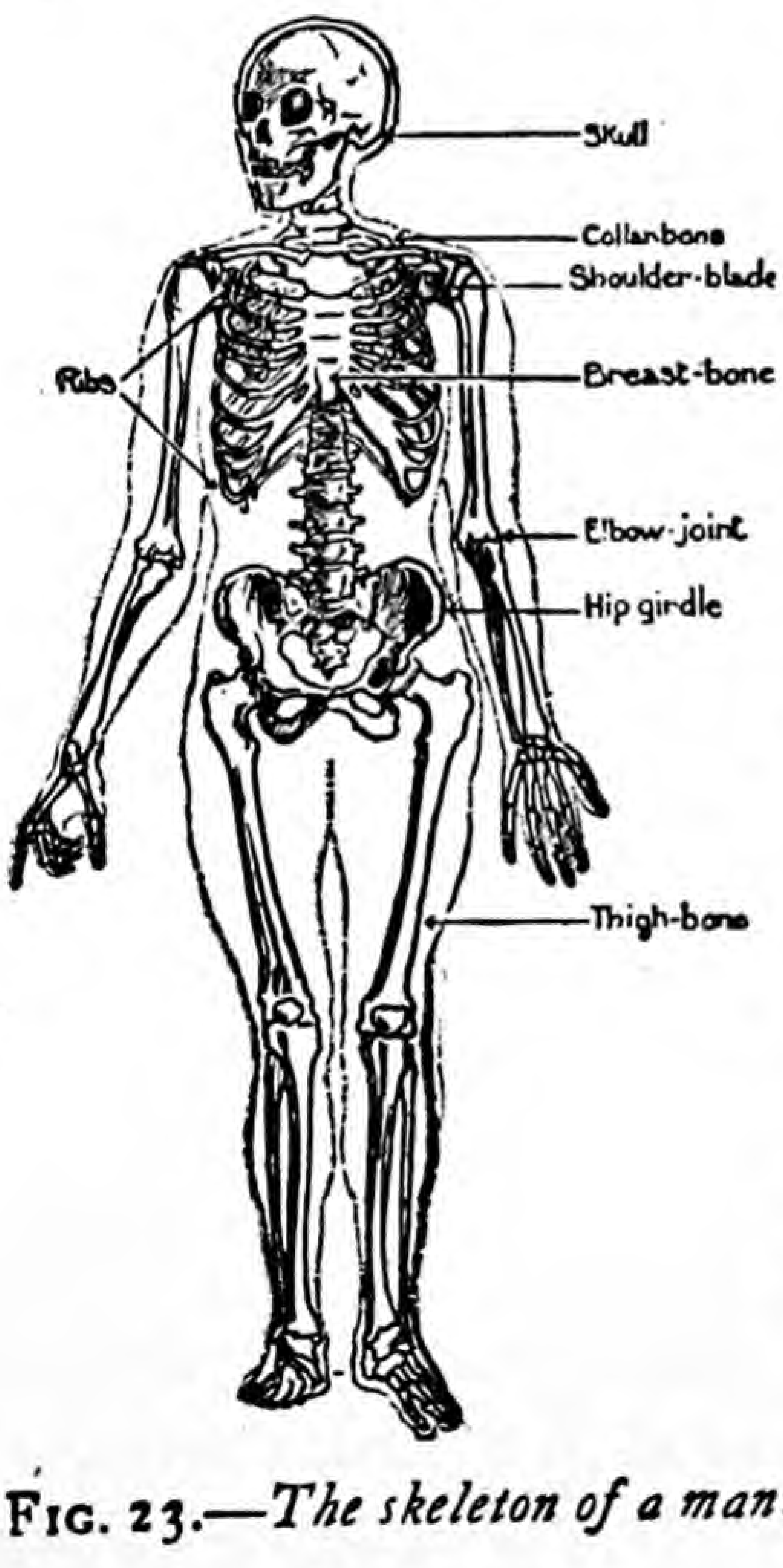


Fig. 23.—*The skeleton of a man.*

Before going on to explain about the movements which our muscles enable us to make, we must say something about the jointed framework of bone we call our skeleton, on which our muscles pull.

As we have seen, muscles pull on bones by means of sinews or tendons. Usually these are definite tough cords, like those at the ends of the biceps; but sometimes a muscle is joined to a bone over a large surface, and then the join is made by a tough sheet of membrane instead of by a cord. That is so, for instance, with the muscles which pull your shoulders back square. These

are attached to the flat surface of your shoulder-blade by a sheet of membrane. Their other ends are fixed to your backbone; so when they contract, your shoulder-blades, as you can easily feel for yourself, are pulled back and in.

When the attachments are regular cords, they may be short, like those the biceps muscle has, or they may be quite long. The tendons by which our fingers straighten are a good example of long attachments. The muscles which pull on them are in your lower arm, so the tendons have to run right across from there to your fingers. You can see them on the back of your hand, and when you straighten a particular finger, you can see its tendon being pulled back towards your arm by its muscle.

People generally cut off the lower part of the legs of a chicken before cooking it, because they have no flesh—that is, no muscles—on them. The muscles that move the toes are right up in the "drumstick" part of the leg. The lower part of the leg has nothing in it except skin, bone, a few blood-vessels and nerves, and tendons. If you can get hold of the cut-off part of a fowl's leg, you can see the tendons, looking like white strings, and by finding which of the strings to pull, you can make the different toes open or shut as you want.

Your bony skeleton does three separate things for you. In the first place, it holds you up. If you had no skeleton, you would collapse in a squashy mass like a jelly-fish out of water. Secondly, it protects some of the most delicate parts of you against damage. Your brain is safely packed away inside the bony box of your skull, and your eyes are not likely to be injured because they are sunk in their sockets, with a rim of bone all round. Your spinal cord, about which we shall read in the next chapter, runs down your backbone inside a bony tunnel, and your heart and

lungs are protected by being inside your ribs, which make a sort of cage of bone. In the third place, your skeleton helps you to move about, by providing a hard framework on which your muscles can pull.

For all three purposes it is necessary for your skeleton to be strong; and it is obviously a good thing for it to be as light as possible for its strength. Your skeleton gets its strength by being almost entirely made of bone, which is very hard and strong through having a great deal of lime in it. Some creatures, like dogfish, have a skeleton made only of gristle, or *cartilage*, which is not nearly so strong as bone; a skeleton of gristle would not be strong enough to support them on land.

Your skeleton is made as light as possible in a very ingenious way, by having all the long bones of your arms and legs hollow instead of solid. Other animals have hollow bones, too, as you can easily see at the butcher's in ox bones which have been sawn across. You might think that this would make them much weaker, but as a matter of fact a hollow tube of something hard, provided its walls are not too thin, is stronger than a solid rod of the same weight and made of the same material. The masts of steamers nowadays are generally made of hollow steel tubes; and hollow steel girders are often used in buildings. So making the long bones hollow saves a great deal of weight. As a matter of fact, the inside of these bones is not just empty. In order not to waste space it is filled with a red pulpy stuff called marrow. This is very good to eat when it is cooked, but it is also very important when it is alive. It is all the time making new blood to take the place of the part of the blood that is getting worn out.

For the purpose of making movements, your skeleton must be made in separate bits, each one of the right shape

and size, and the separate bits must be jointed together so as to be able to move in the way that is wanted and not in other ways.

The joints by which your separate bones are connected are beautifully made for the work they have to do. First of all, it would never do to have two bits of ordinary bone touching each other at a joint. Bone is gritty, and the two pieces would scratch and grit against each other when they moved. So where bones fit into each other they are covered with a layer of special cartilage or gristle, which is shiny and smooth and not so hard as bone. For instance, there is a cap of this sort of stuff at each end of all the long bones of the limbs. You can easily see and feel the shiny cap on the end of the drumstick bone of a fowl.

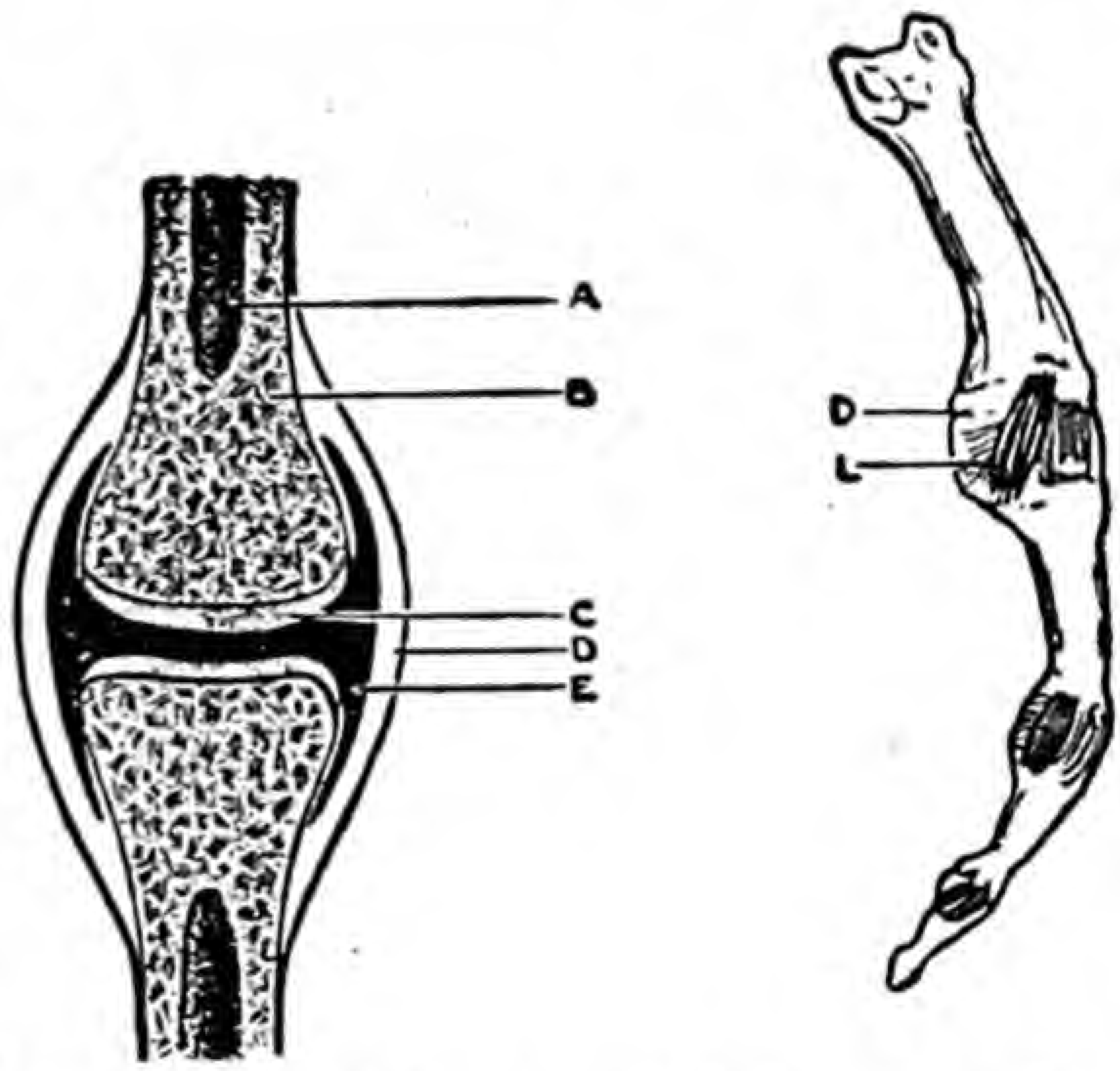


FIG. 24.—*Bones and joints. Left, a diagram of a joint between two long bones cut through. A, the hollow centre of the bone, filled with marrow; B, bone material; C, cap of cartilage; D, tough membrane round the joint; E, lubricating fluid. Right, the bones of a human finger with D, the membrane round the joints, and L, the strong ligaments that prevent sideways bending of the finger.*

Besides this the joints are "oiled." The whole joint is curtained round by a tough membrane which is joined on to the two bones on either side of the joint: and the space inside the curtain is filled with liquid. This is not really oil, but it serves the same purpose as lubricating oil in a machine: it lessens the friction between the solid parts. So, though perhaps it is not quite accurate to talk

of our joints being oiled, we can correctly say that they are lubricated.

When something has to be made so that one part moves on another, the joint between the two parts has to be made in a definite way. For instance, a door has hinges, which will let it open and shut, but will not let it move in any other direction. In the case of a camera on a tripod, on the other hand, you may want to point it in any direction. For this, people make what are called *universal joints*, which consist of a ball fitting into a socket; the ball can be fixed in place by tightening a screw. If, on the other hand, you want one part to move round another like a wheel on its axle, you make a hole in it, and pivot it on a peg that goes through the hole.

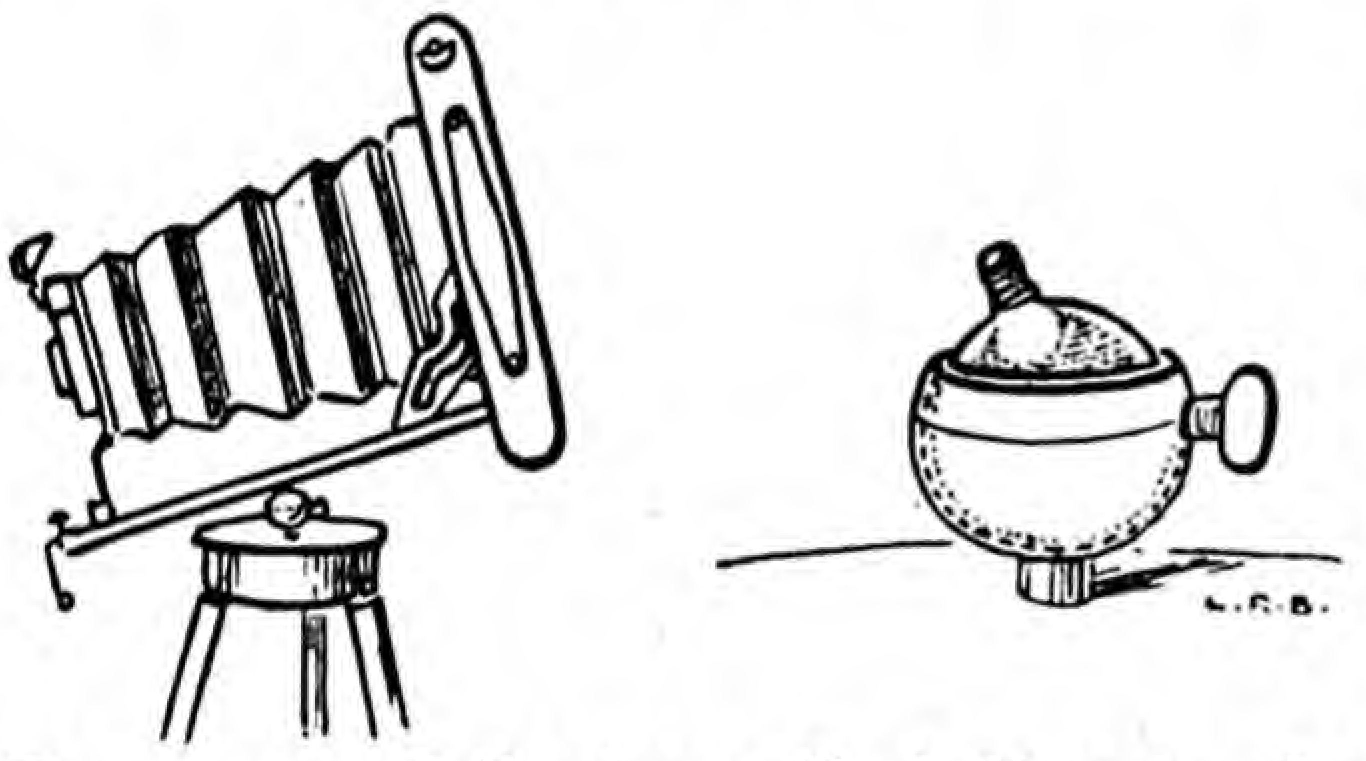


FIG. 25.—*A "universal" ball-and-socket joint, and how it can be used with a camera.*

The joints on your body are made in different ways, according to the movements they are meant to allow. For instance, your elbow is very like a hinge. It will allow your lower arm to bend up in one particular direction, but not to move sideways. Nor can it bend backwards, for when your arm is straight, your funny-bone comes up against the bone of the upper arm and acts as a stop. Another hinge-joint is the one which joins your lower jaw to your skull: it is so arranged that your jaw can move up and down, but hardly at all sideways. (In a cow, this joint is made differently, so that the jaw can slide a good way from side to side, as you can see if you watch a cow chewing. This helps the cow to

grind its food fine between its upper and lower grinding teeth.)

Your hip-joint, on the other hand, is a ball-and-socket "universal" joint. The head of your thigh-bone is a knob of bone with a beautifully rounded end, and this round end fits into a cup-shaped socket in the hip-bone, or *pelvis* as it is called in science. So the thigh can move in any direction—backwards and forwards, as when you run, or sideways, as when you are doing physical exercises and have to stick one leg out horizontally while standing on the other, or even round in a circle, as you can make it do if you lie on your back.

A good example of a pivot joint is the one which lets you turn your head from side to side. This consists of a peg of bone sticking up from the second of the bones of which your backbone is made (*vertebræ*, as they are generally called), and fitting into a hole in the first vertebra above it. The hole is surrounded by bone on three sides, and on the fourth is closed by a strong sheet of the stuff of which tendons are made. By using the right muscles, the head together with the first vertebra can be turned from side to side round the peg of bone which acts as a pivot.

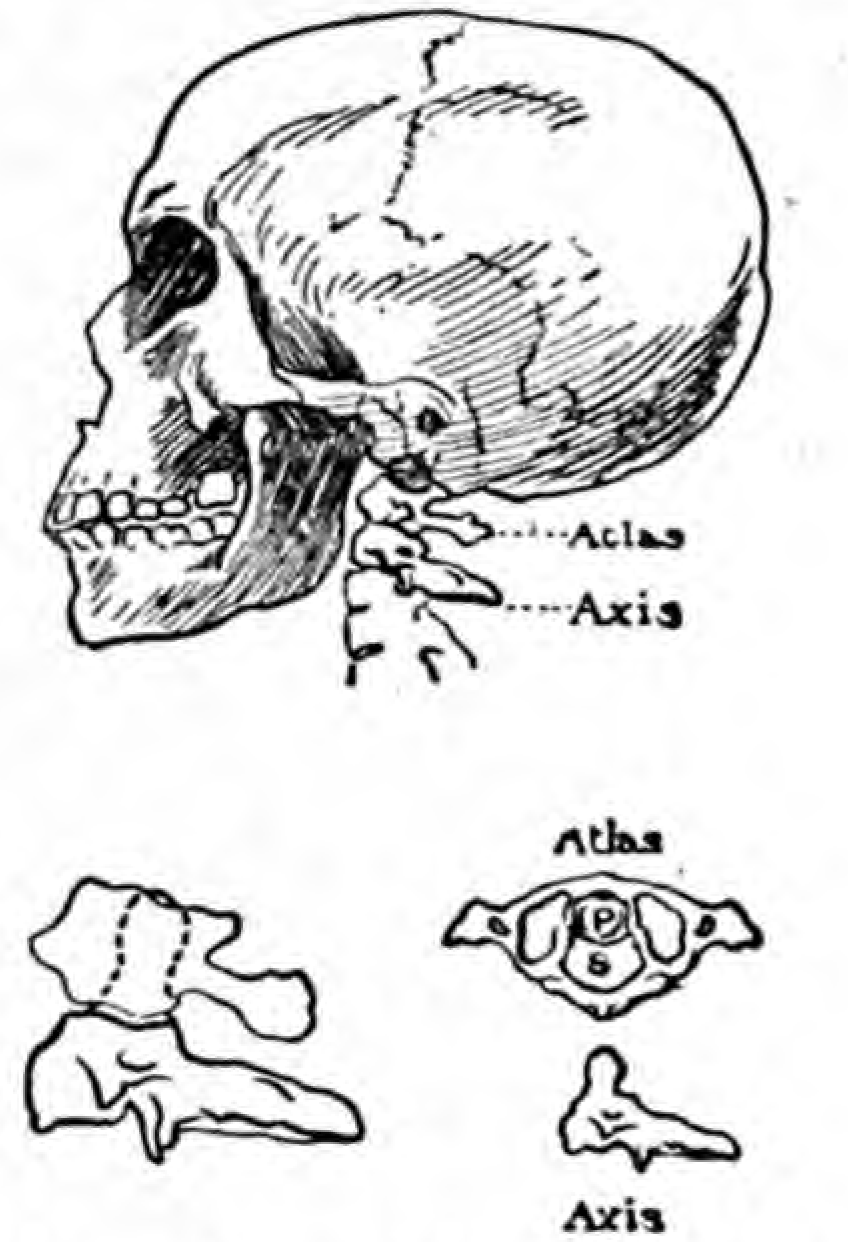


FIG. 26.—*How the head moves. Above, a man's skull with the first two vertebræ of his backbone, the atlas and the axis. Below, left, to show how the peg of the axis vertebra fits into the atlas. Below, right, the atlas vertebra seen from above;* P, *the peg of the axis separated by a tough band of membrane from* S, *the space through which the spinal cord passes. Under the atlas is the axis vertebra seen from the left side.*

When you want to nod your head backwards or forwards, you use another joint. The nodding joint is between the skull and the first vertebra, and is a sort of shallow hinge-joint. The first vertebra supports your head, and so is called the *atlas* vertebra, after the giant named Atlas in the Greek story, who was supposed to carry the world on his shoulders. The second is called the *axis* vertebra, because its bony peg provides the axis or centre round which the head turns.

You will find that you can turn your head through about a right angle to either side. Some birds, like owls, can manage to look almost straight behind their backs; but no creature can turn its head, or any other part of its body, through a complete circle, much less make it go round and round like a wheel. A wheel-joint is impossible in an animal, because the moving part which goes round could not be supplied with blood-vessels and nerves—they would get broken as it went round; also the tough membrane which keeps the lubricating fluid in place would get torn. Wheels are a purely human invention: the only animals with wheels are toy animals.

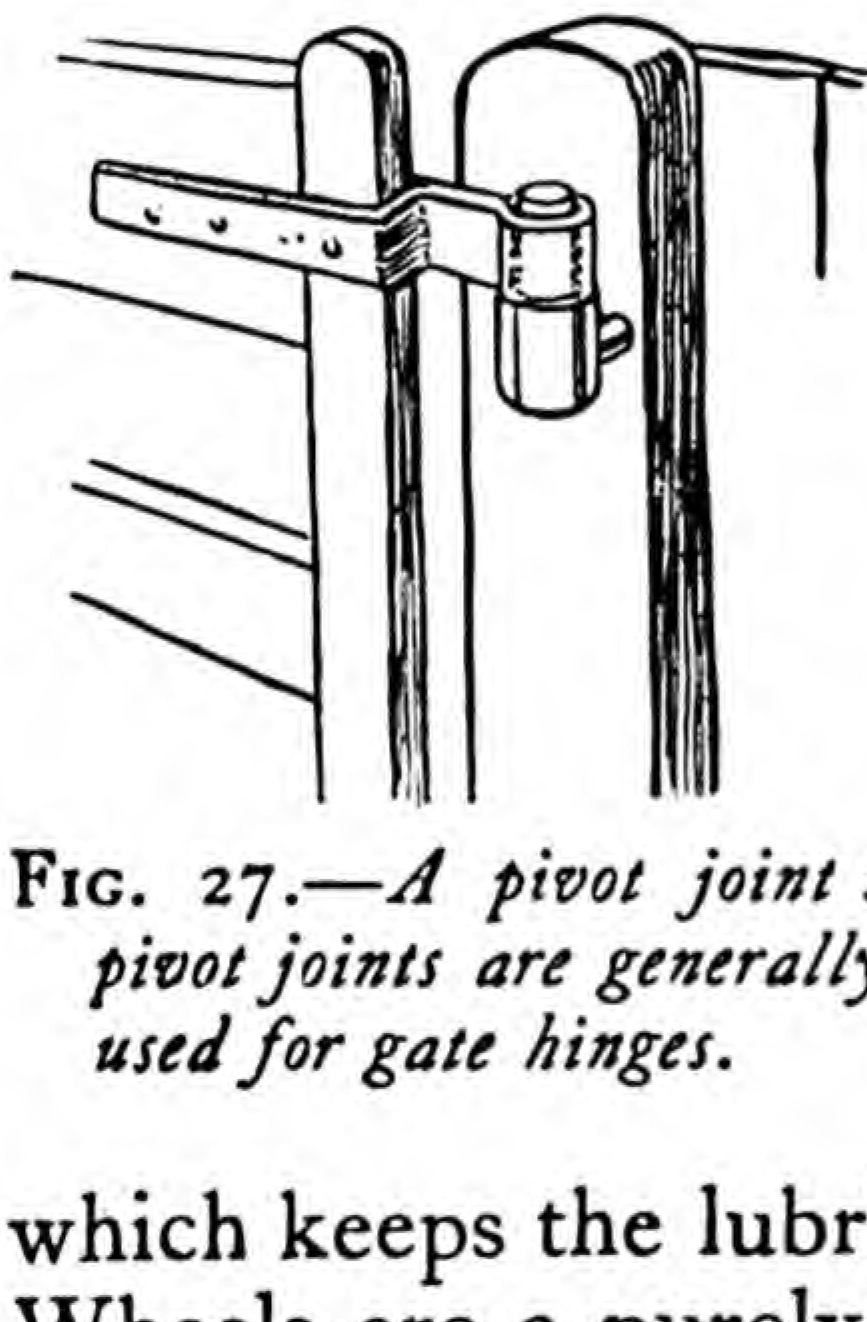


FIG. 27.—*A pivot joint: pivot joints are generally used for gate hinges.*

Finally, there is one other part of a joint to talk about. In order to prevent the bones from being pulled apart, they are tied together by strong bands of the stuff of which tendons are made. These bands are called *ligaments*, from a Latin word for binding or tying things. The ligaments not only keep the bones together; they are so arranged as to allow them to move in the right

direction, but to prevent them being wrenched in a wrong direction.

A very bad wrench may be too much for a joint, and then the ligaments are stretched or torn and the bones are forced out of place. When this happens, we say that the joint has been *dislocated*. A bad fall may dislocate your shoulder-joint, which means that the top of your arm comes out of its socket in the shoulder-blade. Jaws, too, may get dislocated, and then you cannot shut your mouth until the doctor, or somebody who knows how, forces them back into place. Sometimes people dislocate their jaws by yawning very widely.

Dislocating a joint is always an unpleasant accident for us. But some snakes have joints which are made to be dislocated. Snakes do not use their teeth for biting pieces off their food, but only to prevent their prey from escaping. They also have very small heads. So in order to be able to eat large animals, many snakes have jaws which are dislocated every time they feed. While a snake of this sort is swallowing its prey, the two halves of the jaw come apart in front, and the back of the jaw at each side comes right out of its socket. The ligaments of the jaws are very elastic, and bring the parts of the jaw back into their proper places

FIG. 28.—*The bones of your skull are jointed so as to allow no movement. Above, a human skull seen from the top; below, part of the dove-tailed jointing of the skull-bones, magnified.*

when the meal is finished. By this means a python is able to swallow a goat or an antelope whole, even though it is many times as big as its own head.

Finally, we must remember that there are some places in our bodies where bones have to be joined so as to allow no movement. The best example of this is the bones of the skull. In the head of a tiny baby you can see soft places where the bones have not yet joined up properly. Later they grow together, and join up in a very wonderful way, just like pieces of a jigsaw puzzle, so that they are firmly locked together and cannot possibly be pulled or pushed apart.

Levers

Now we must come back to the movements which our muscles enable us to make. To understand these, we must understand something about levers; for the muscles use the bones as levers.

When you use a chisel to open the lid of a box, or a crowbar to pry a heavy stone out of the ground, you are using a lever. This seems a simple enough thing to do. But when you think that without the chisel your fingers would be helpless to open the box, and that to lift the stone would be quite beyond your unaided powers; and when you find that no animals have ever used levers in this sort of way, then you will realise that the discovery of how to use levers, which primitive man made thousands of years ago, was a very important one.

A lever is something stiff and rigid, used for applying a force at one place in order to lift a weight or overcome a resistance at another place. You pull on one end of the crowbar, and the other end forces the stone up. For this to happen, there must be a fixed point on which the lever

can rest: you use a stone or something hard near the boulder you want to lift, and press on this. Such a fixed point is called a *fulcrum*. In all levers there is always a place where the force is applied, a place where the force is made to move something, and a fulcrum about which the lever turns.

FIG. 29.—*The big stone is too heavy for the man to move by himself. But by using a crowbar as a lever, he can lift it.*

The leverage you get from a lever depends on the distances between the fulcrum and the other two points. Consider a pair of ordinary scales, such as those figured in Book I, p. 70 and p. 108. These act as a very simple lever—a bar of steel with two arms of equal length, balanced on a knife-edge of steel (or about a steel pin run through it) with two pans hanging from its ends. On one pan you put the weight to be lifted—say some sugar. In the other you apply the force, by putting in weights until they balance the sugar. The knife-edge is the fulcrum.

In this case, the fulcrum is just half-way between the two ends of the lever; and so the weights in the two pans must be just equal if the scales are to balance. But if one arm of the bar were longer than the other, you could only get it to balance by putting unequal weights in the two pans. You can easily test this for yourself by rigging up a home-made arrangement with a bar of wood balancing on a nail stuck through it. If the nail is twice as far from one end as it is from the other, you only need to hang half

as heavy a weight on the long end as on the short end, in order to keep the bar balanced level.

This principle is used in a machine called a steelyard, which is really nothing else but a balance with arms of unequal length. One very simple kind of steelyard is often used for weighing the carcasses of animals, and another more complicated sort you can see being used for weighing luggage at railway stations. In a steelyard, one

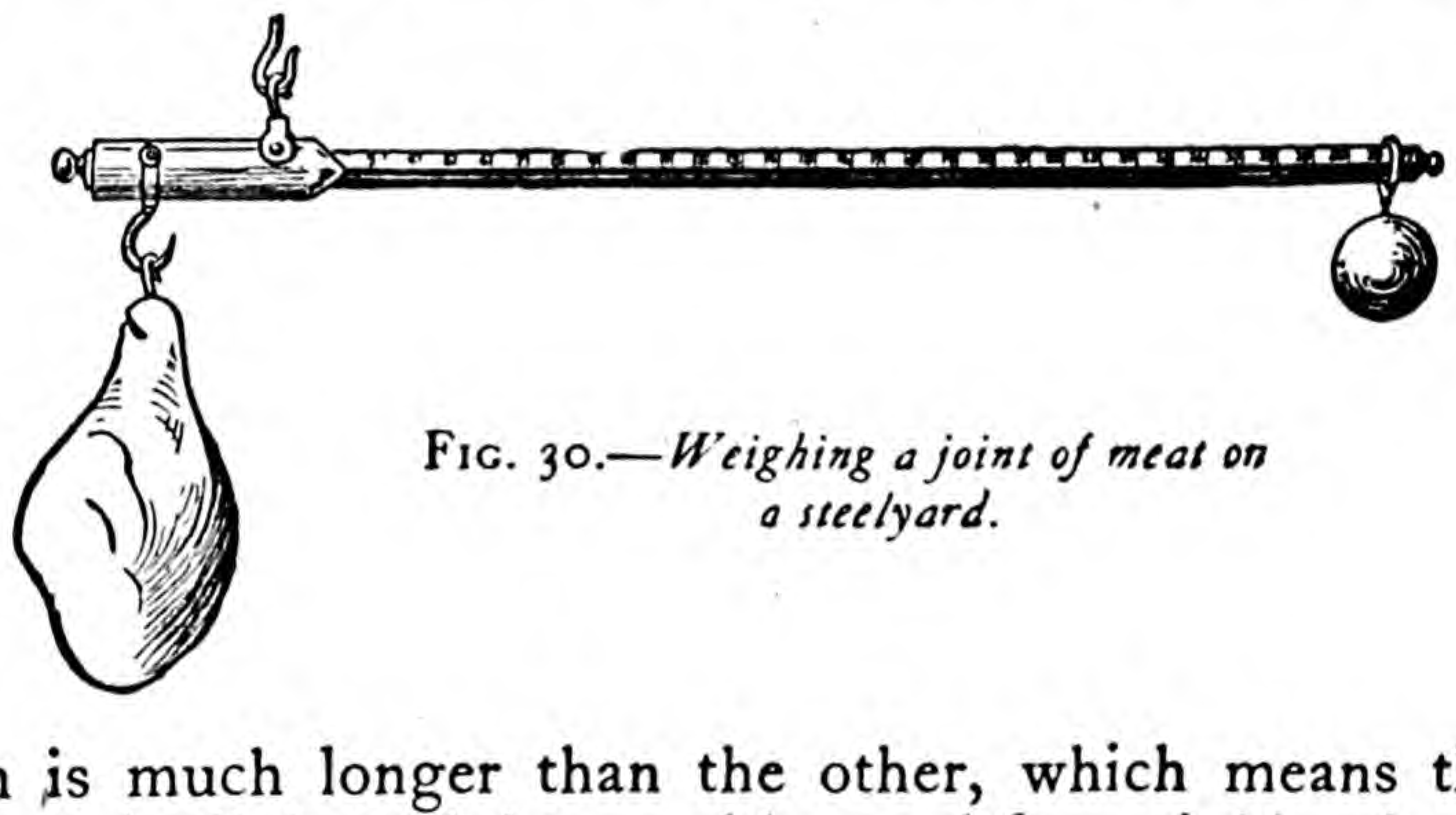


FIG. 30.—*Weighing a joint of meat on a steelyard.*

arm is much longer than the other, which means that only quite light weights need be used for weighing heavy things.

We have seen that if one arm of a balance is twice as long as the other, one pound at the end of the long arm will balance two pounds at the end of the short arm. If the long arm is four times as long as the short one, a pound at its end will balance four pounds on the short arm, and so on. The rule is that for the balance to be level, the number given by multiplying the weight by the distance from the fulcrum must be the same on both sides.

Suppose in a butcher's steelyard the long arm was 32 inches long, the other arm, the short arm, 4 inches long.

Then, for every pound of what you were weighing at the end of the short arm, you would only need to put 2 ounces at the end of the long arm: $16 \times 4 = 2 \times 32$. To balance a carcass weighing a hundredweight (112 lbs.) you would only need a 14-lb. weight at the end of the long arm. We say that the length of the long arm gives the weight at its end a *mechanical advantage*. The amount of the mechanical advantage is measured by the number of times the long arm is longer than the short one.

However, we must remember that in a steelyard of this pattern, in order to pull the heavy weight up a given distance, the light weight at the end of the long arm has to move a distance eight times as great, and therefore has to go eight times as far and as fast as the heavy weight at the end of the short arm. You can easily see this for yourself by making drawings of a steelyard when it is tilted and when it is level.

This is the principle underlying the usefulness of levers. With a crowbar, you put your fulcrum, a stone or a piece of wood, close to the boulder or packing-case you want to move. If the boulder weighs a thousand pounds, and the distance from the fulcrum to your hands is ten times as long as from the fulcrum to where the crowbar presses against the boulder, the crowbar gives you a mechanical advantage of ten, and you can lift the boulder by using a force equal to a hundred pounds. But for each inch you lift the boulder, you have to move your end of the crowbar down 10 inches.

The fulcrum need not be between the force and the weight. For instance, if you are using a screw-driver to pry open the lid of a box, you can use it in three ways. Either you can work it just like the crowbar with the boulder, using the edge of the box as the fulcrum, and

pulling down on the handle of the screw-driver. Or, after the lid is a little loosened, you can push the screw-driver a little in along one side of the box, and pull up on the handle. Then the fulcrum is where the tip of the screw-driver presses against the side of the box, and the weight to be lifted is in the middle between the fulcrum and the power. Or, finally, if you like, you can make the handle the fulcrum, by holding it firmly with one hand, and then you can apply the force by pulling up with the other hand

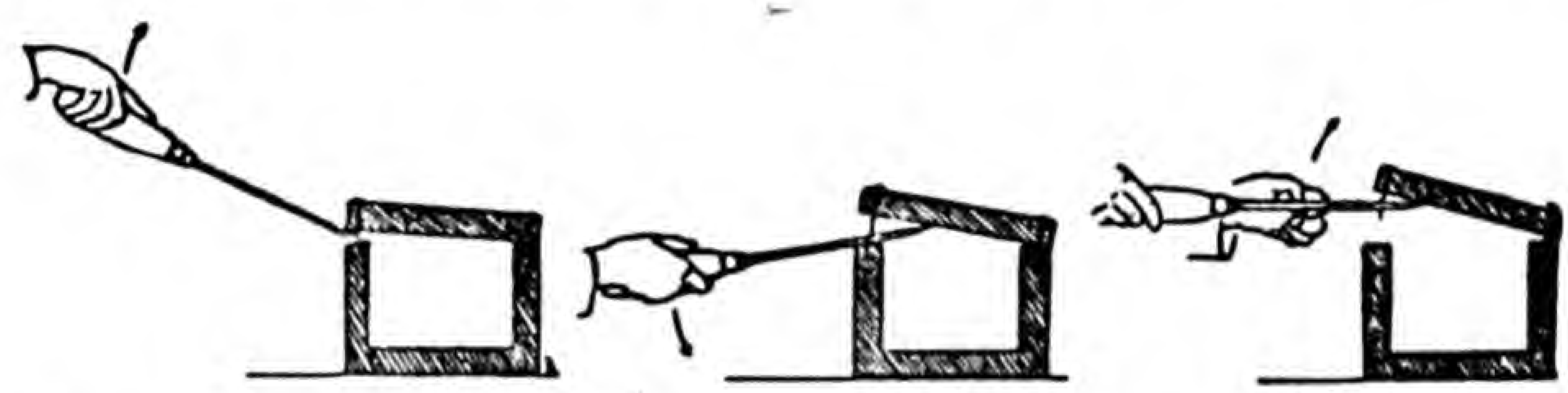


FIG. 31.—*Three ways of using a screw-driver as a lever to open a box.*

on the base of the steel part; now the force is in the middle. But, wherever the power is applied, the principle is always the same—the ratio of the force used to the weight lifted equals the ratio of the distance from the weight to the fulcrum to the distance from the force to the fulcrum. It is a rule-of-three sum.

How Muscles Work in the Body

Now let us go back to the levers in your body. When you bend your elbow, the biceps helps to provide the power needed, and the bones of your forearm are arranged to work as a lever, on which the force acts. Think of a particular action—say bending the arm straight up with a pound weight in your hand—and let us see just how the leverage works. The elbow-joint, as we have seen, is built so as to act like a hinge, allowing the lower arm to

move freely upon the upper arm in one direction, but not in others. The biceps is attached to the bones of the lower arm about $1\frac{1}{4}$ inches from a man's elbow-joint. But the weight to be lifted—the pound in his hand—is much further away from the place where the biceps exerts its pull—about 11 inches, which makes $12\frac{1}{2}$ inches from the elbow-joint. When his biceps contracts, the elbow-joint acts as the fixed point or fulcrum, and the lower arm has to move up. With a crowbar a very heavy weight can be lifted with a comparatively small force; whereas to lift a weight in your hand, your muscle must exert a bigger force—a force equal to about $12 \div 1\frac{1}{4} = 10$ times the weight. Instead of giving you a mechanical advantage, your arm-lever works at a mechanical disadvantage.

What is the good of it, then? You will see the answer if you remember that with the crowbar the man has to push his end down a long way in order to lift the weight at the other end only a little way. Your arm-muscle has to exert a force ten times as great as the weight you want to lift: but the weight is made to move up ten times as quickly as it otherwise would. Your arm-lever, in fact, is not designed to help you lift big weights with the expenditure of little energy: it is designed to allow you to move your hand up as quickly as possible.

When you nod your head, the arrangement is rather like a steelyard. The muscles that make your head nod forwards are attached to your jaw, much farther away from the fulcrum than the muscles at the back of your neck that make it nod back. So the muscles for nodding back must be more powerful than those for nodding forwards.

Your foot, again, is a good example of a lever. The calf-muscle of your leg is fixed to your heel by a strong tendon. (This is called the Achilles tendon, from a legend about the

Greek hero Achilles, whose only weak spot was in his heel.) When you raise yourself on your toes, the calf-muscle contracts and pulls the heel up. The weight to be lifted is you, and this bears down on your foot through your shin-bone. The fulcrum is the ball of your foot as it presses against the ground, and the lever is the whole arch of your foot, from

FIG. 32.—*The bones of the foot act as a lever when you lift your heel. The calf-muscle pulls on the heel-bone; the toes make the fulcrum, and the weight of the body, pressing down through the shin-bone, is raised.*

FIG. 33.—*Negroes usually have longer heels than Europeans, and so need less muscle in the calf of their legs.*

heel to toes. Here the weight is between the power and the fulcrum. In this case there is a slight mechanical advantage, because the distance from tip of heel to ball of foot is a fraction greater than from ball of foot to base of shin-bone. Obviously, the longer the heel, the greater the mechanical advantage, and so the less powerful will be the muscles required. Negroes generally have calf-muscles

which to us look poorly developed. But this is because they generally have long heels, and so do not need such big muscles.

It is interesting to try and think out for yourselves in what way other parts of your skeleton can act as levers—for instance, when you straighten your leg to kick a ball; when you close your mouth with a snap; when you lift one leg sideways, and so on.

All the muscles which are joined to parts of your skeleton help to move you from place to place, or to move parts of your body. But besides these you have many other muscles which are used for another purpose, namely to move things from place to place inside your body. These muscles are not joined to bones, but are arranged in the form of sheets or tubes or bags. At the bottom of your chest, between your lungs and your stomach, is a sheet of muscle called the diaphragm. When it is relaxed it is arched up, but when it contracts it has to straighten out. This expands the lungs and sucks air into them. So the diaphragm muscle helps to move air. There are muscles which make a sheath round the gullet and intestine, and it is they which drive the food along your digestive tube. This is done by what we call waves of contraction passing along the sheath of muscles: the muscles at one point of the tube contract, and then those a little further down, and so on. The effect is as if you were to squeeze a rubber tube in your hand, and then move your hand steadily along it, squeezing all the time. But the arrangement in our body is a better one than this, for while the muscles at one place are contracting, those just beyond are made to relax, as is shown in the picture. This makes it even easier for the food or drink to be squeezed along.

So, when you swallow, your food or drink does not just fall down your gullet into your stomach, but is seized hold of by the pressure of the muscles and forced along. This is how animals can drink with their heads lower than their bodies. The animal forces water into its gullet by contracting the muscles in the floor of its mouth. Then the muscles at the top of the gullet contract so much that they close the gullet-tube and the water cannot flow back. And then from here a wave of contraction starts, and the water is pushed along the gullet. The water is actually driven uphill; and, as a matter of fact, you too can eat or drink uphill if you chose to put yourself into an uncomfortable position.

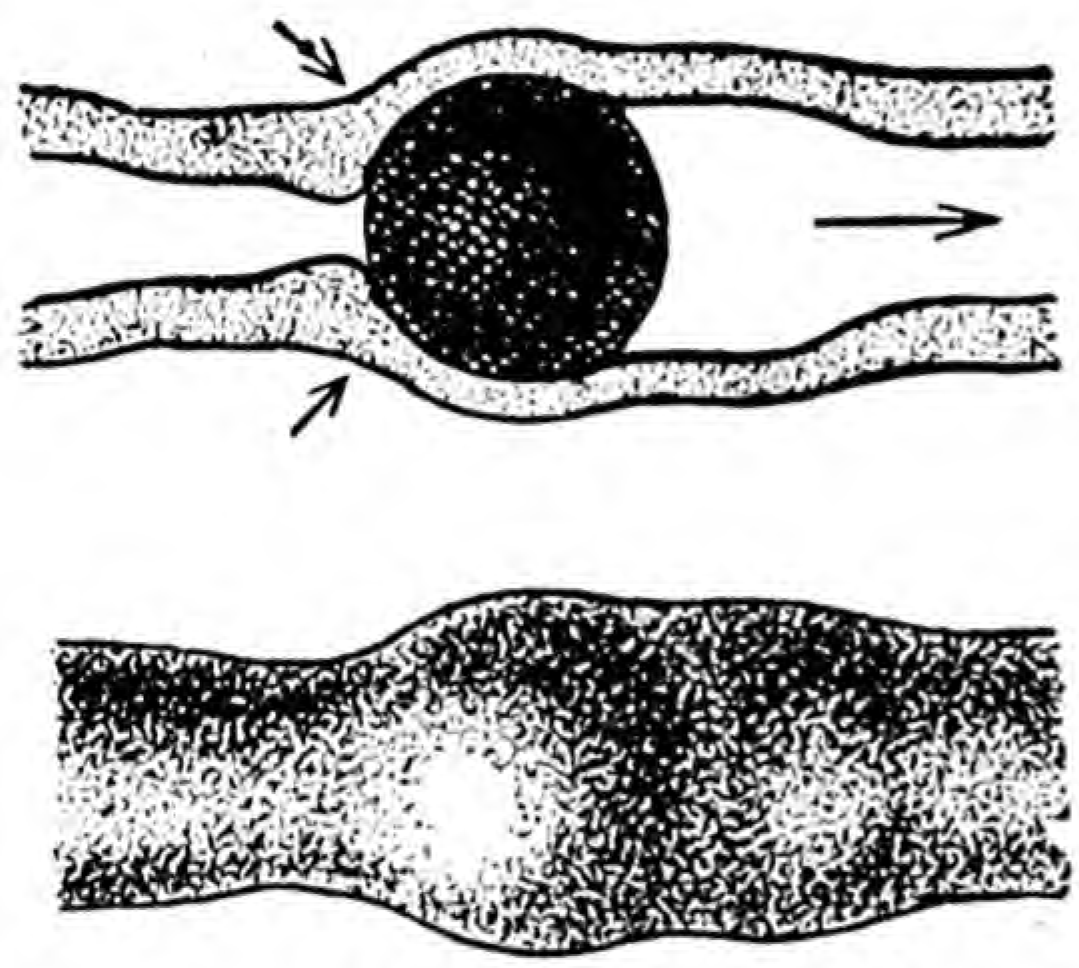


FIG. 34.—*How food travels down our gullet. The muscles just above the ball of food squeeze tightly, while those just below it are relaxed.*

The stomach, again, consists mainly of a bag of muscle, and its contractions serve to churn the food up thoroughly and mix it with the digestive juices. The heart, too, is a bag of muscle, only more complicated than the stomach, which is used to squirt the blood out and drive it through the blood-pipes all round the body. Most of the blood-vessels also have tubes of muscle round them: if the muscle is contracted, the vessel gets narrower, and lets less blood through. By this means the flow of blood to different parts can be adjusted as required, just as the flow of water in irrigation systems can be adjusted by opening or shutting sluices. For instance, after a heavy meal, you often feel rather chilly. This is because the blood-vessels in your

digestive tube have been opened up full, and those in your muscles and skin have been narrowed so as to get more blood where it is wanted to absorb your food. There is less blood than usual near your surface, and so your skin will cool more rapidly.

How Different Animals Move

So far we have only spoken of the movements of our own bodies. But some animals move by quite different methods. All the most complicated animals have a jointed skeleton, the parts of which act as levers when the muscles pull on them. But while the backboned animals have most of their skeletons inside, as we do (though sometimes, as in tortoises and armadillos, part of the skeleton is outside), creatures like crabs and insects have most of theirs on the outside. A good example to study is the big claw of a crab or lobster. If you break open the biggest joint of the claw, you will find that the inside is almost entirely taken up by two muscles, one big and one small. The "finger" of the claw is hinged to the big joint. The bigger muscle pulls on the inner side of the base of the finger, the smaller one on the outer side, and the hinge, which acts as the fulcrum, is in between. The

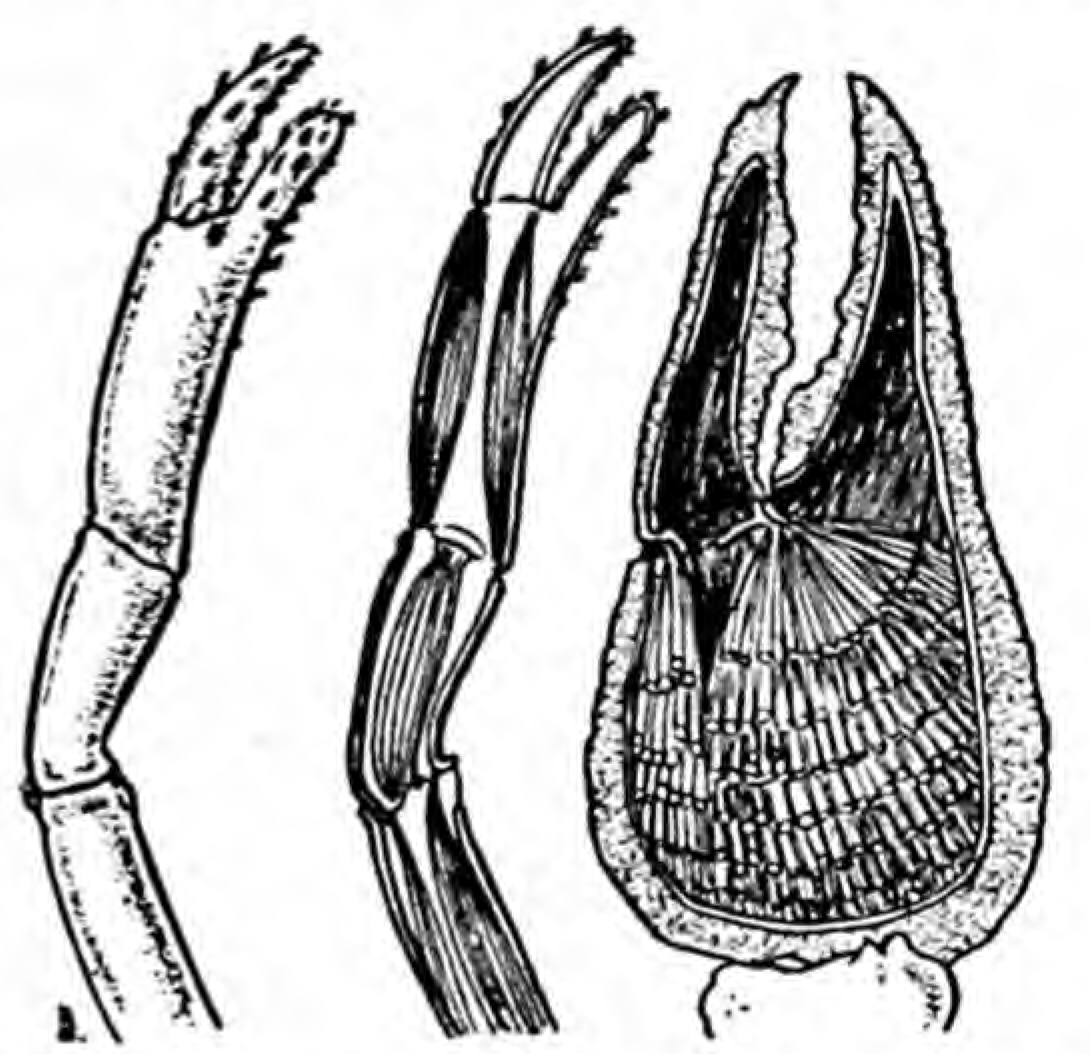


FIG. 35.—*How lobsters move their limbs. Left, the first walking leg of a lobster. Centre, the same cut open to show the two muscles in each joint: in the middle joint, the second muscle was on the near side, and has been cut away. Right, the big claw cut open to show the large muscle which closes the claw and the small one which opens it.*

big muscle pulls the movable finger inwards against the pointed end of the big joint, to nip an enemy: the lobster needs to nip as powerfully as possible, so this muscle is big. The other muscle need only be quite small, because all it has to do is to pull the "finger" away when the animal wants to stop nipping. The muscles actually pull on flat plates of skeleton which stick down from the finger-joint into the inside of the big joint. You can see these when you are eating a lobster or a crab. In each of the other joints of the claw, and in the joints of the walking legs, there is the same sort of arrangement, but the two muscles are about the same size. When one muscle pulls, the next joint further out from the body is bent; when the other pulls, the next joint is straightened. The hinge between each pair of joints is set in a different direction; so by bending the various joints by various amounts, the leg can be put into any desired position. The legs of insects work in just the same way.

Some of the simpler animals, though they have muscles, do not have any skeleton to provide levers for the muscles to work on. An earthworm is a common example. At first sight it is hard to see how such an animal can move in a definite direction; and yet it does. If you watch an earthworm crawling, you will see that it makes its body, especially in the front part, alternately thinner and thicker. It is able to do this because everywhere under its skin it has two layers of muscles, one with the fibres running round the body, the other with the fibres running along the length of the body. When the muscles running along the body contract, they shorten the body and make it fatter, while the other set squeeze the body and make it thinner and longer.

This explains how the body changes its shape, but not

how it moves along. To understand this, take a worm in your hand and run your fingers along it, first from head to tail, and then from tail to head. You will find that it is quite smooth the first way, but feels rough and scratchy the other way. This is because there are numbers of tiny bristles made of horn sticking out of the worm's body, and arranged so that they point backwards. These catch in the roughnesses of whatever the worm is crawling on. Since they point backwards, the worm's body can never slip back, though it is able to slip forward. In just the same way, an ear of wild barley has its long prickly bristles (or *awns* as they are called) all pointing one way. If you put it up your sleeve with the awns pointing downwards, the movements of your arm and your clothes press it first in one direction, then in the other; but the awns will only allow it to move one way, and so it travels right up to your shoulder.

Another way of moving by muscles is found in some water animals. They suck water into themselves gently, and then violently squirt it out. As a result, they themselves move in the opposite direction. We can understand how this is so by thinking of a rifle. When the powder in a cartridge explodes, it turns into gas, which expands violently and tries to escape in all directions. It can escape down the barrel by driving the bullet before it; but meanwhile it also pushes in the opposite direction, where it cannot escape (if it could escape at this end, there would be very little force on the bullet). This push in the direction opposite to that of the bullet makes the rifle *recoil*, as it is called, and it kicks back against the shoulder of the man who is shooting: it is important to hold the butt of the rifle firmly against the shoulder, otherwise the recoil may produce a bad bruise. If the

rifle is fired while suspended from a wire, it will swing back violently. Big guns are made so that the whole barrel can move backwards, and its recoil is taken up by powerful springs. It is the recoil which makes rockets shoot up into the air. Here there is no bullet: the gases produced when the rocket is lit can only escape in one direction, and so the whole rocket is forced in the opposite direction, as we saw in Chapter I.

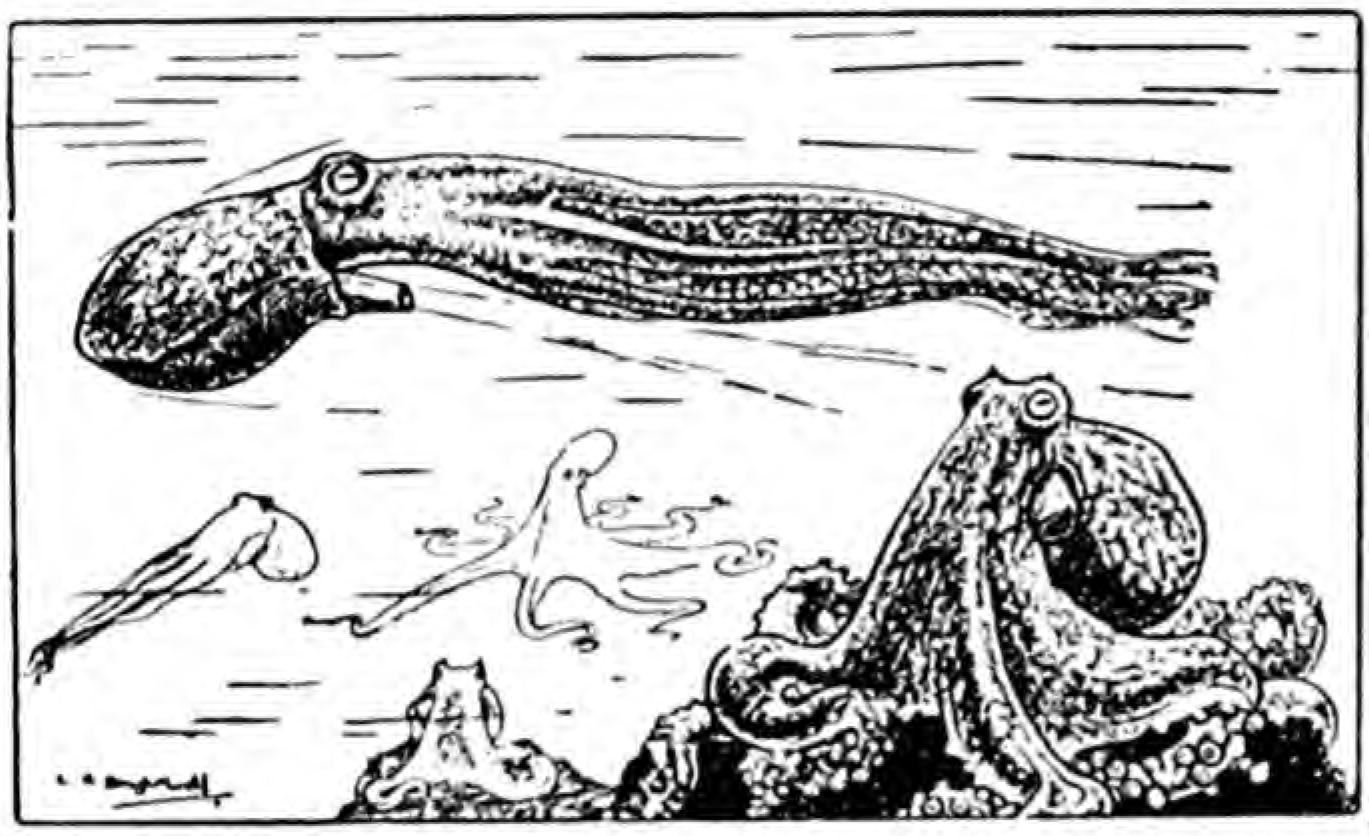


FIG. 36.—*The octopus swims backwards by squirting out a jet of water forwards through a tube under its head.*

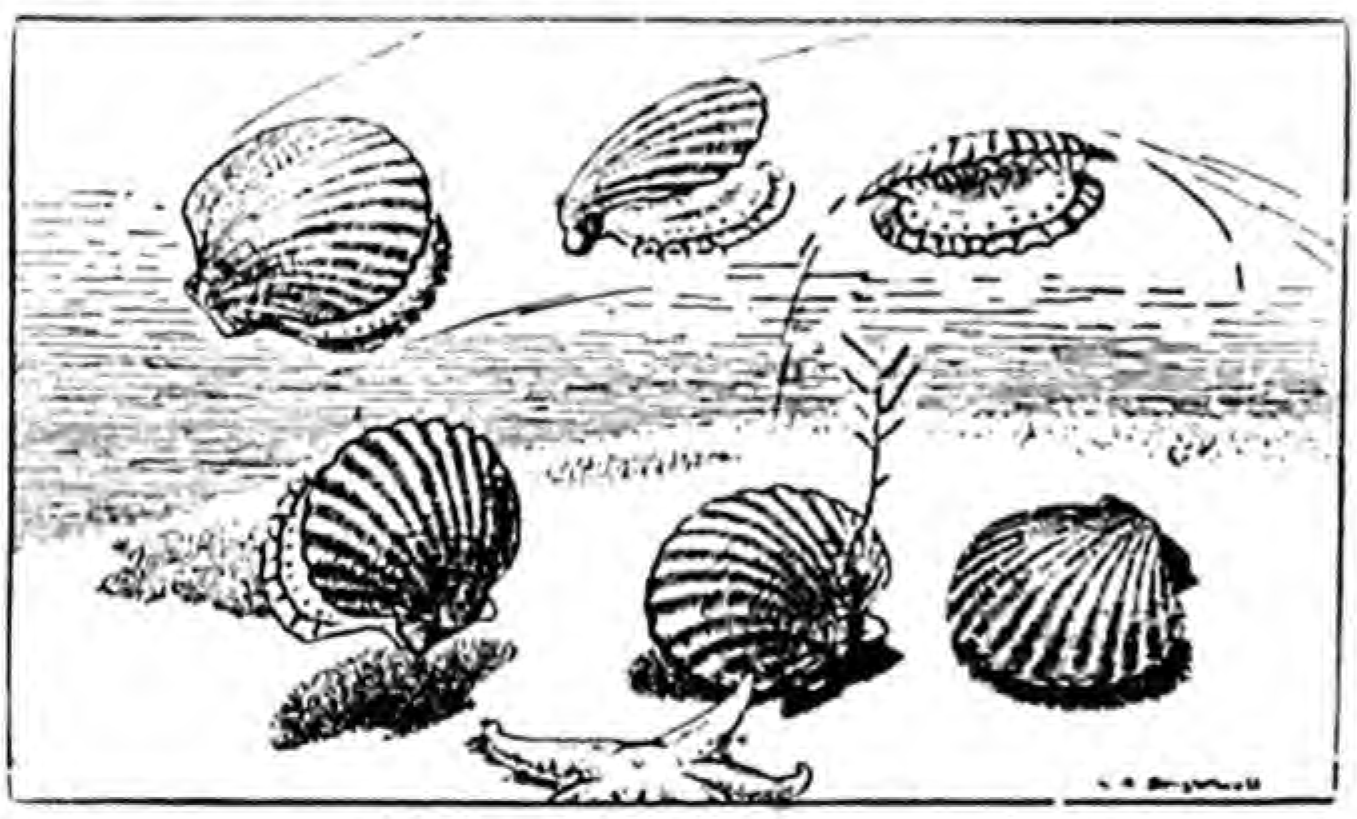


FIG. 37.—*How scallops swim. Two are resting on the sea-bottom; the other four are flipping themselves through the water. Scallops are killed and eaten by starfishes, and when a starfish is near they smell it and try to escape by swimming away.*

It is the same sort of thing that happens with animals which move about by squirting water. The best examples are octopuses and cuttlefish. In these animals the water is violently squirted out forwards through a tube below the neck region, and so the animal shoots quickly backwards.

Scallops do the same sort of thing by clapping their shells together. They have little eyes all round the edge of their body, and when they are alarmed by a sudden shadow falling on these, or in other ways, they flip themselves backwards through the water. Thanks to this

method, they are the only shell-fish which can move at all fast.

Jelly-fish, too, have a similar arrangement: they are bell-shaped, and their muscles are in two sets, one for opening the bell, and so taking water into it, the other for closing the bell, and so squirting water out. The closing action is the more violent, and as a result the animal moves away from the direction in which the bell opens (Fig. 123).

Not all animals move by muscles. Many move by cilia, the microscopic hairs or whip-lashes which were described in Part I. Only animals which live in water can move in this way, because cilia would dry up in air. And the method will only work with very small animals, as cilia are always very tiny. If you put a newly hatched tadpole in a glass dish, you will see it move very slowly along without moving its body at all. This is because it is covered with cilia. They are so small that you cannot see them except with a microscope, but there are so many of them that their lashing moves the tadpole along. However, it is too big for its cilia to move it except very slowly, and after a short time it begins to use its muscles to swim with.

Even in ourselves, cilia are still used to move things from place to place inside our bodies. For instance, the air passages inside our lungs are covered with cilia, all lashing outwards towards the windpipe. They are covered with a film of moisture, and the cilia are so small that they can work in the thickness of this thin film. But even though they are so small, they are useful. If any tiny particles of dust or dirt get into our lungs, they catch in the moist film, and then the beating of the cilia slowly drives them outwards. If it were not for this, our lungs would soon get clogged with dust.

There are many other ways in which animals move. You have only to think of birds and insects using their wings to fly in the air, and fish swimming with side-to-side movements of their bodies. But these movements are complicated and not at all easy to understand.

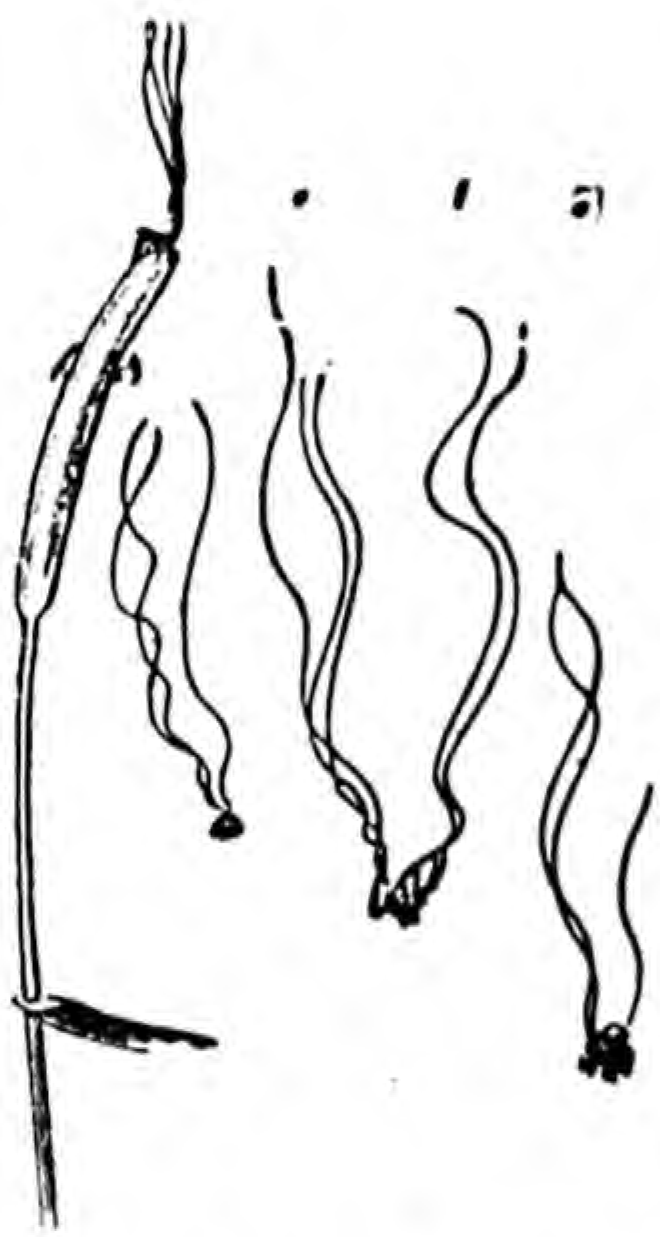


FIG. 38. — *Gossamer spiders parachuting. To take off, they climb to the top of a plant when there is a rising current of air, spin out two or more fine threads, and let go.*

There are some animals and plants which get free transport in currents of air or water. Tropical sea-animals sometimes drift as far as England or Norway in the Gulf Stream. Coconuts and other woody fruits often float for hundreds of miles and may still sprout after being thrown ashore. It is not only microscopic bacteria which can float about on the wind. Dandelion seeds and thistledown get blown for miles, and there are cases known where a violent storm has sucked up water with fish in it and dropped them miles away. On clear autumn mornings, baby gossamer spiders send out a long thread of silk. As the ground is warmed up by the sun, the air near it is heated and rises and carries up the gossamer threads, with the spiders hanging from them; so with the aid of these parachutes, the young spiders are carried far and wide.

But these cases are rare. Usually the animal has to move itself about. It does this with the aid either of muscles or of cilia, and it gets the energy needed for the working of these from the slow combustion of its food.

CHAPTER III

HOW THE BODY MACHINE IS CONTROLLED

Muscles are Controlled by Nerves—The Brain—How We See—The Brain helps in Seeing—Seeing Colours—Hearing, Smelling and Tasting—Touch, Temperature and Pain—Inside Information—The Different Worlds in which Animals Live

Muscles are Controlled by Nerves

IN the first two chapters we learned about the supply of food and oxygen to the different parts of the body, and then about the way in which muscles work. What we have said there explains how you can move at all: but it does not explain how you move in just the right way. It would be no good if your muscles contracted just anyhow. Picking up a pencil off your desk to write with seems a simple thing to do. But if you think of what must be going on inside your arm, you will realise that a great deal of living machinery must be set in action, and in a very complicated and delicate way. The triceps muscle at the back of your upper arm must contract to straighten out the lower arm. Muscles in the lower arm must get busy and pull on your wrist so as to get your hand into the right position. In every joint of every one of your fingers, muscles must be contracting, each one just so much, so as to hold the pencil. And, of course, you must put out your hand to just where the pencil is lying: it would be no good if you put it only an inch to one side.

Muscles do not get to work just when and how the fancy takes them. They contract when a pull or a squeeze

is wanted, and stay slack and loose when it is not wanted. They contract just enough to give the amount of pull that is needed. This is because they are connected with *nerves*, and a muscle will only work when it gets a message through a nerve.

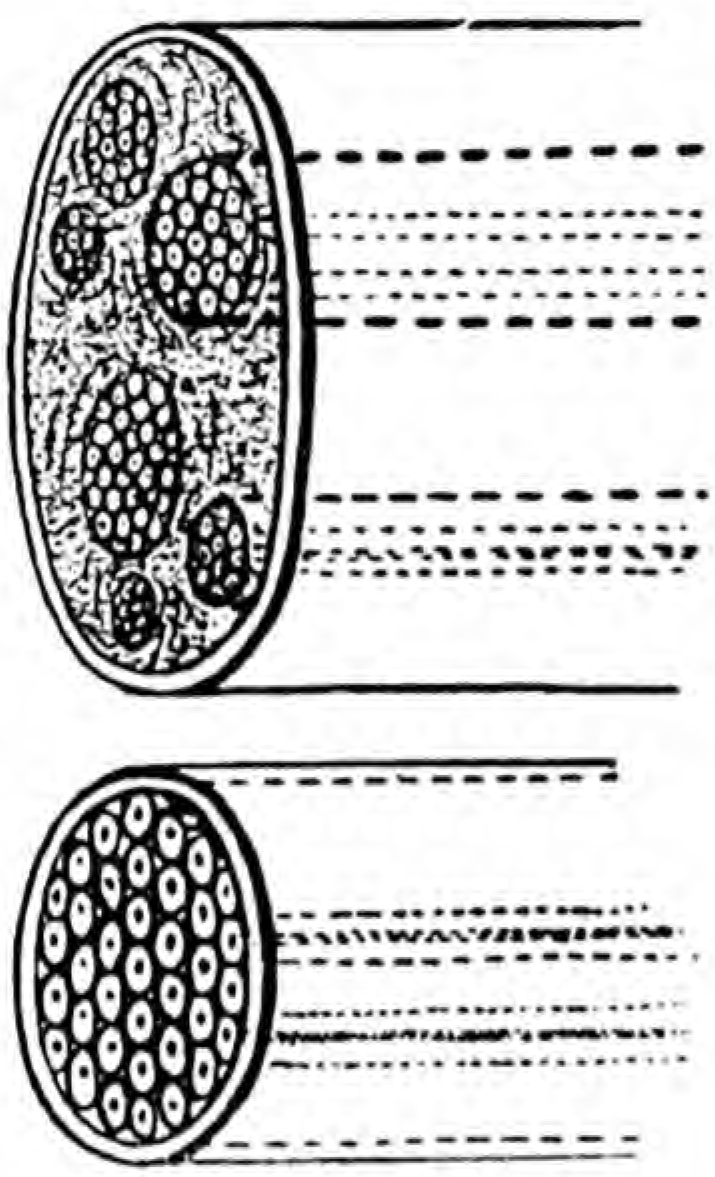


FIG. 39.—*Diagrams of a nerve (above, much magnified) and a telephone cable cut across. The nerve has a tough sheath outside and several bundles of nerve fibres inside. Each nerve fibre has its own little sheath. In the telephone cable, each wire has its own insulating sheath, and the whole is protected by a lead tube.*

Nerves look something like pieces of white string. They run out of holes in the skull and the backbone and branch all over the body. If you look at a small nerve from a dead frog or rabbit under the microscope (it is best to tease it up with needles in a weak solution of salt) you will see that it is made of hundreds of tiny fibres. These nerve fibres run inside the nerve like the wires inside a telephone cable, and the whole bundle is tied round by a protecting sheath, again just as a cable is.

If you trace the nerves back to the inside of the backbone or skull, as can easily be done in a dead rabbit or frog, you will find that they join up there with a mass of material that fills up almost the whole of the tube inside the backbone and the big space inside the skull. The mass of nerve substance inside the backbone is rod-shaped, and is called the *spinal cord*. Inside the skull, it swells out into quite a big organ, with a number of complicated parts. This is the brain. The spinal cord and the brain are joined together: the spinal cord comes out of the skull

by a big hole at its hind end. The whole mass is soft, and is more pink than the white nerves, though it, too, contains thousands of nerve fibres. The brain, the spinal cord, and the nerves all together are called the *nervous system*: and the brain and the spinal cord without the nerves are called the *central nervous system*. As we shall see, the whole thing is rather like a telephone system: the central part (the brain and the spinal cord) is like the exchanges, the nerves like the cables and wires outside.

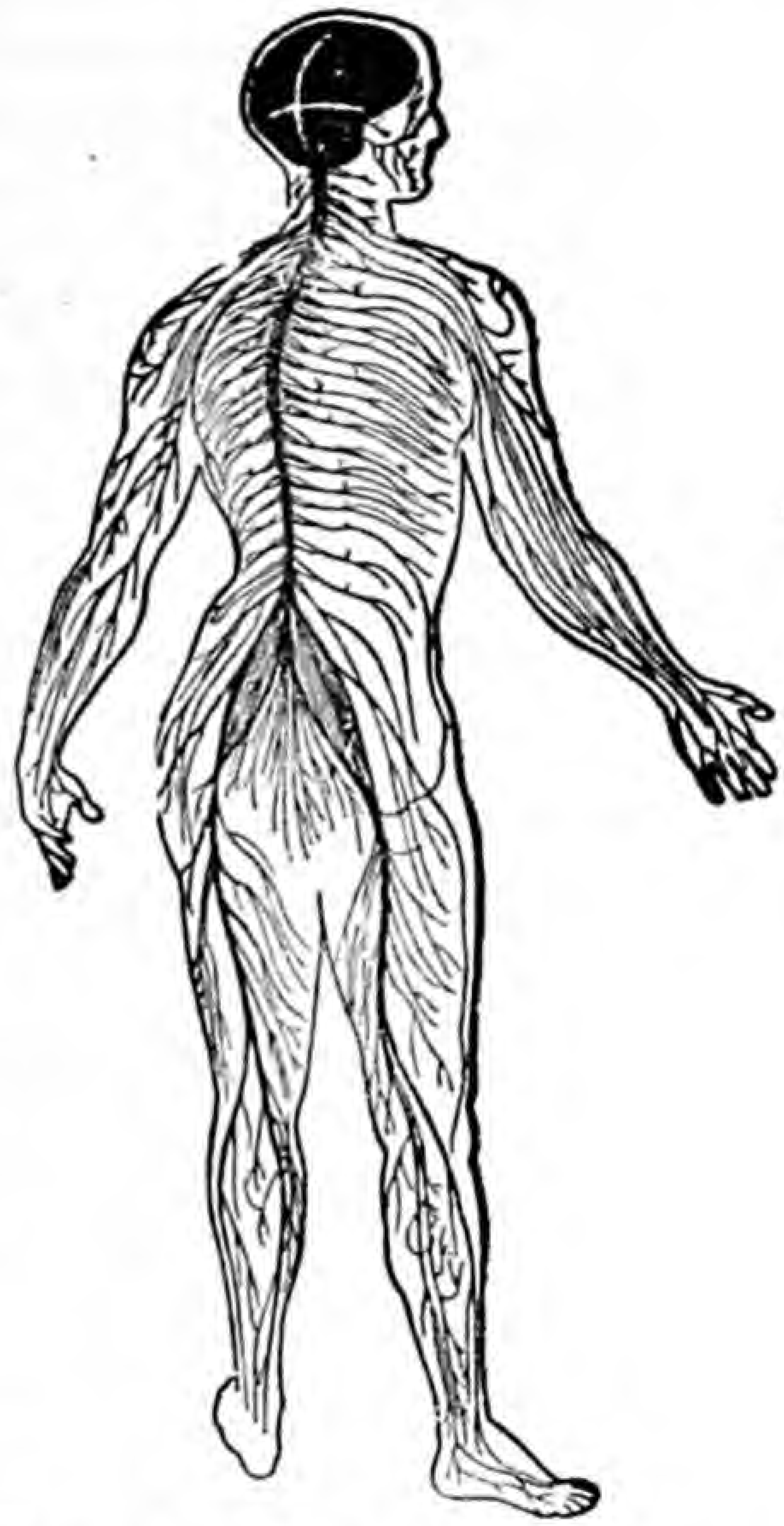


FIG. 40.—*The nervous system of a man. The central part of the nervous system is the brain in the head and the spinal cord in the back From these, the nerves come out and run to all parts of the body.*

The nerves branch and branch, some of the fibres going off in one branch, others in another, until the final branches consist of very fine threads with only a few fibres in each. In many nerves, these final branches end right inside muscles. And the business of such nerves is to make the muscles contract (or in some cases to stop them contracting and make them go loose and flabby). This we can easily see for ourselves. If, in a frog which has just been killed, you peel the skin off one of its legs, you will see a big muscle in the calf of the leg, with a white nerve, about the size of coarse thread, running to it. If you pinch this nerve

lightly with tweezers, or give it a small electric shock, the muscle will contract, and this will make the foot straighten out. Even if you cut the nerve at the top of the thigh, and then carefully dissect the nerve and muscle out of the body, doing things to the nerve will still make the muscle twitch and contract; and this will go on for quite a long time if you keep the nerve and muscle from drying up.

So your muscles contract when their nerves bring them messages to get busy. But what makes your nerves bring the messages just when they are wanted? This we can understand when we learn that not all nerves take messages outwards from the brain or spinal cord to organs like muscles, which *do* things. Only about half of them do this. The rest are connected with organs that are getting to *know* things, such as your eye or your ear or the microscopic organs in your tongue with which you taste. These nerves are taking messages inwards to the brain and spinal cord. The nerves that take messages outwards are called *motor nerves*, from the Latin word for moving, because their messages make you move; and those that take the messages inwards are called *sensory nerves*, because their messages come from the organs of your various senses. People used to think they had only five senses: but, as we shall see later, they really have a good many more—sight, hearing, smell, balance, taste, touch, heat, cold and some others.

Inside the central part of the nervous system, the sensory nerves are connected with the motor nerves in the same sort of way that a telephone call is connected at the exchange with the wire for the number which is asked for. So the incoming message, which tells your body what is happening outside, is flashed out again to your

muscles and glands so that you take the right action—or at least take some action.

Suppose you are lying down quietly, and someone pricks your foot with a pin. Immediately you will bend your leg up so as to get your foot away. The pin has pressed against tiny sense-organs in your skin which have to do with the sensations of touch and pain. These are connected with nerve fibres which run in sensory nerves to your spinal cord. There they are connected with the inner ends of another set of nerve fibres which run out in motor nerves and end in various muscles of your legs. So the message from the skin is switched through to the leg-muscles, and you bend your leg up. The message does not go the shortest way from the sense-organs in your leg to the muscles in your leg, but has to come right up the spinal cord and down again. In the same way, if you want to call up your next-door neighbour on the telephone, your message has to go perhaps two miles into the exchange and two miles out again.

The nerve message takes time. Along your nerves it goes at about 400 feet a second, and there is a little time used up making the connections in the spinal cord. So allowing about 3 feet each way for the message to travel, it will be about 1/60th of a second before your muscles can get to work to start pulling your leg away from the pin—and in the front legs of a giraffe, for instance, it would be about 1/15th of a second.

In a cold-blooded animal like a frog, by the way, nerve messages go much slower—only about a quarter as fast as in your body. Doubtless this was true also for the huge reptiles that once lived on the earth. You would have needed a very large and sharp nail instead of a pin to get any kick out of the hind leg of one of these; and

as there would be nearly 40 feet for the message to travel there and back, the kick could not begin till nearly half a second after the prick.

Perhaps you will be thinking, what about the pain from the pin—is it not really that which makes you take your leg away? The answer is that even when no pain can be felt, the leg still draws itself away from a pin-prick. Sometimes people have had accidents or wounds which have broken their spinal cord, but have not killed them. A man to whom this has happened cannot feel anything in his legs, and yet the legs are still alive. If you were to prick his foot, he would draw his leg away just as you would; but he would not feel any pain. He would not even know he had drawn his leg up (unless he saw what the leg had done). As long as the lower part of the spinal cord is alive, with its nerves making the proper connections, the movements of the leg will follow quite automatically on the prick of the pin.

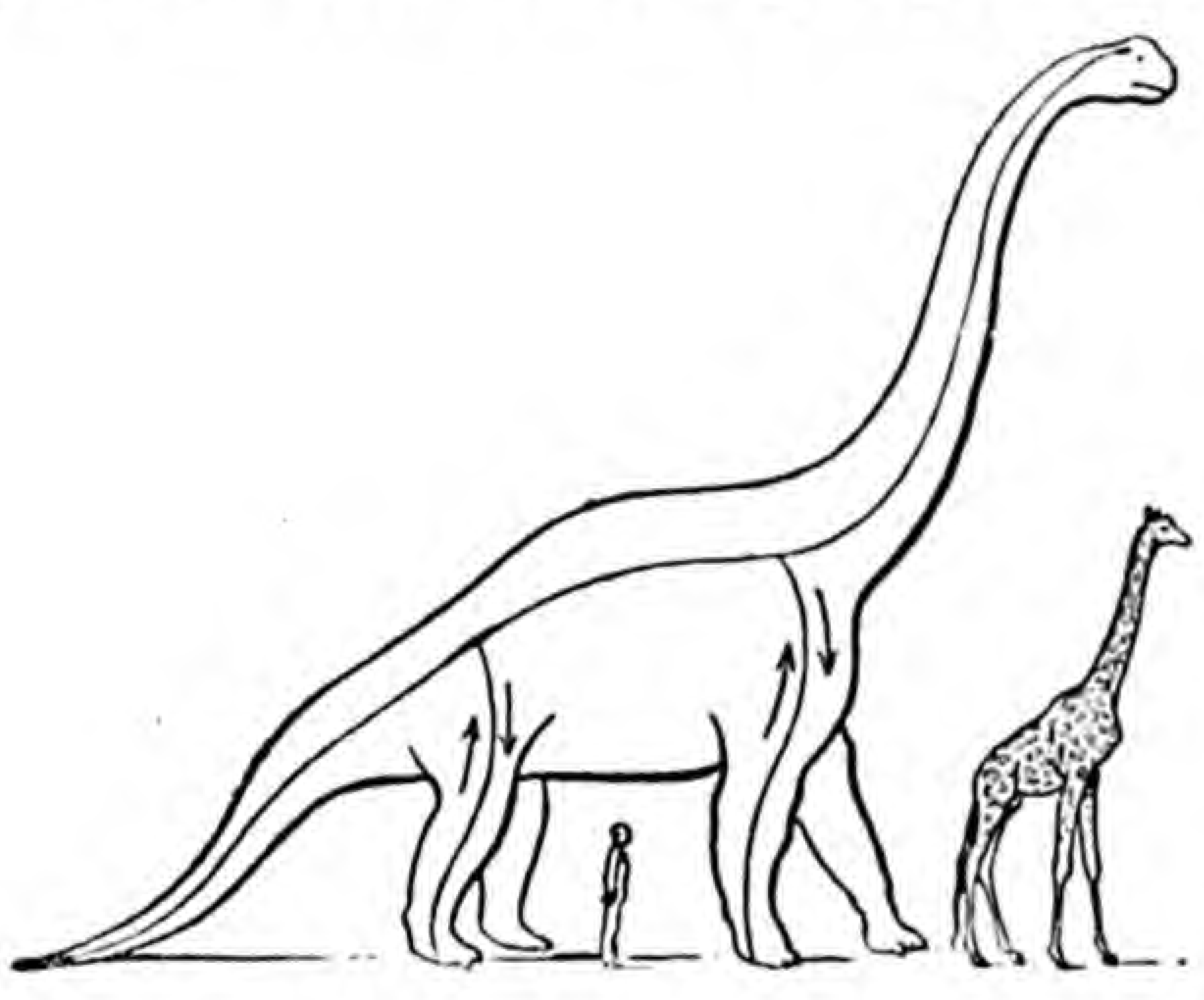


FIG. 41.—*The extinct reptile called Branchiosaurus stood 18 feet at the shoulder. To get from the touch organs in its foot back to the muscles in its foot, a nerve message would have to travel about 30 feet. The man and the giraffe are put in to show the scale.*

THE BRAIN

When you feel pain it has nothing to do with your spinal cord: it has to do with your brain. The sensory nerves from your leg, besides making direct connections

through the spinal cord with your leg's motor nerves, also connect with nerve fibres which run right up the spinal cord to your brain. Similarly, other fibres run down from the brain and make connection with the motor nerves to the leg. So there is a double connection between the leg's sensory and motor nerves—one direct and short, through the spinal cord only, and the other long and roundabout, by way of the brain. (Things are really even more complicated, but this gives the main idea.)

But, you may perhaps be thinking, if the processes which have to do with pain go on in the brain, how is it that you feel the pain of the pin-prick in your foot and not in your head? It is not easy to give a simple answer to this: one can only say that this is how the brain works. It makes you feel the pain at the place where the damage is being done. In just the same way, as we shall find out later, the processes concerned with the sensation of sight also go on in your brain, though it is your eye which makes it possible for you to see them. In this case your brain works in an even more interesting way. It makes a picture which seems to be right outside you—not in your head, nor yet in your eye. We say that the brain *refers* the pain to where the body is damaged, and *refers* things it sees through the eyes to the position in which they really are.

There is a curious example of the way the brain will refer pain. If a man with rheumatism in his leg has had to have the leg cut off, sometimes, when the weather is damp, he will seem to feel pain in his leg, though that is no longer there! What happens is that the damp affects the sensory nerve in the stump of his leg; this takes messages to the brain, and the brain, having been used to

referring messages of this sort to rheumatic pains in the leg, automatically goes on doing so.

You all know that if you really wanted to, you could stand a pin-prick on your foot—at least if it was a fairly gentle one. But this means an effort. Your leg wants to draw itself up, but you make it stay and bear the pain. In the same way, though sneezing and coughing can happen quite automatically, you can generally stop yourself from doing either if you try hard enough—for instance, if you are hiding and you do not want to give your hiding-place away by making a noise. It is with your brain that you do this. The short connections through your spinal cord lead to automatic actions; but by means of the long connections through your brain you can, up to a point, control or change or stop these actions.

Two other very important things which you do with your brain are to learn and to remember. All your learning goes on in your brain, both the sort of learning which comes from study and thinking, and the sort which just comes from practice in everyday life. A jelly-fish never learns anything, because it has no arrangements for learning. It is made to work in a particular way, and it always works in that way, whatever experience it may have been through.

Many things which seem quite automatic are really learnt by the brain. When you put something good to eat in your mouth, your mouth waters. This does not have to be learnt; it is an automatic action. But if you are used to hearing a gong go before dinner, the sound of the gong will generally make your mouth water without your thinking of it. Your brain has learnt to connect the two happenings. Animals learn to do tricks in the same sort of way:

they are taught by being given food, or rewarded in some other way, after they have done the trick properly.

Your brain has to learn to control your movements. If you watch a baby, you will see how much it has to learn about where the parts of its body are and how to put them where it wants them to go. Perhaps it wants to poke a jammy finger into its mouth, but smears it on its cheek instead. Or it wants to take hold of its own toes, but only succeeds after two or three grabs in the wrong place. You had to learn all this for yourself once, but thanks to your brain you have now learnt it so well that

FIG. 42.—*Man has a very big brain. The heads and brains of a man and a horse, drawn on the same scale.*

you can do it without thinking about it any more; but if you want to make a new kind of movement, like skating, you have to use your brain to learn it.

All your memories, too, are somehow stored up in your brain. Your spinal cord is not able to remember things, or to learn things or do things differently: it would always do everything the same way if it were not controlled by the brain. The brain acts something like the head office of a big trading concern with branches all over the country, while the spinal cord acts something like a district office. The district office is all the time getting reports from the

branch shops in its district to say which things sell well and which sell badly, what customers ask for and what they complain about; and it acts on this information by sending goods in various quantities to the branch shops, and giving directions and orders to the shop managers. But at any moment the district office is liable to get orders from the head office telling them to do something quite different from what they would have done if left to themselves. This is because the head office will be getting reports from the whole country, and will have experts who are studying trade conditions. So the head office will have a much better view of the situation as a whole, and may decide, for instance, to push cheap goods when the branch office would have gone on trying to sell expensive ones.

In the same sort of way, when something tickles your throat the direct nerve connections are so arranged as to make your coughing machinery get into action. But meanwhile your brain may be getting messages from your eyes, say, or your ears, which quite alter the situation and make it important for you not to cough: or it may remember that you are hiding and so want to keep quiet. Then the motor nerves to the muscles by which you cough will have messages sent down to them from the brain, which are stronger than the messages from the tickle in your throat, and will prevent you coughing.

There are many different parts of the brain. For instance, there is one dealing with sight, another with hearing, another with feeling, another with thinking, others with sending messages down the spinal cord and out to various parts of the body; and the different parts of the brain can act on one another. This sounds complicated; but it cannot help being complicated. A human brain is by far the most complicated thing in the world—

much more than any machine made by man, much more so than anything else in nature, and all we can do here is to make a start in understanding it.

All your memories, all your sensations, all your feelings, all the knowledge you gain, all the will-power you have—this has all got to do with your brain. So too have many other things you know nothing about, which just go on automatically. For instance, though with one part of your brain you can make yourself control your breathing, usually another part decides just how fast and how deep it shall be, without your having to think at all. Another part of your brain arranges for you, without your being conscious of it, how your muscles shall work together to keep your body upright and prevent you losing your balance. The more you learn about the brain, the more wonderful you will find it; and you will realise that such a complicated arrangement requires proper treatment, and that you need to take a good deal of trouble to learn just how best to use this marvellous bit of machinery which nature has provided for you.

How We See

Now we must say something about the sense-organs—the arrangements which give us information about what is happening in the world around us.

Let us consider sight first. Our two eyes are really very like photographic cameras. To understand them, it is a good thing to get some ox eyes from the butcher's and cut them open with a razor. Cut one in two downwards so as to separate its right from its left halves, and cut another so as to separate the front from the back half. At the same time get hold of a camera and look at its various parts.

The most important parts of the camera are the lens for making an image of what you want to photograph, and the sensitive film for recording the image. To get a sharp image on the film, the lens must be at a definite distance from the surface of the film. This distance differs according to the distance of the object you are photographing. The nearer the object is to the lens, the further from the film must the lens be. To allow for this, all except the cheapest cameras have a focussing arrangement to move the lens backwards and forwards.

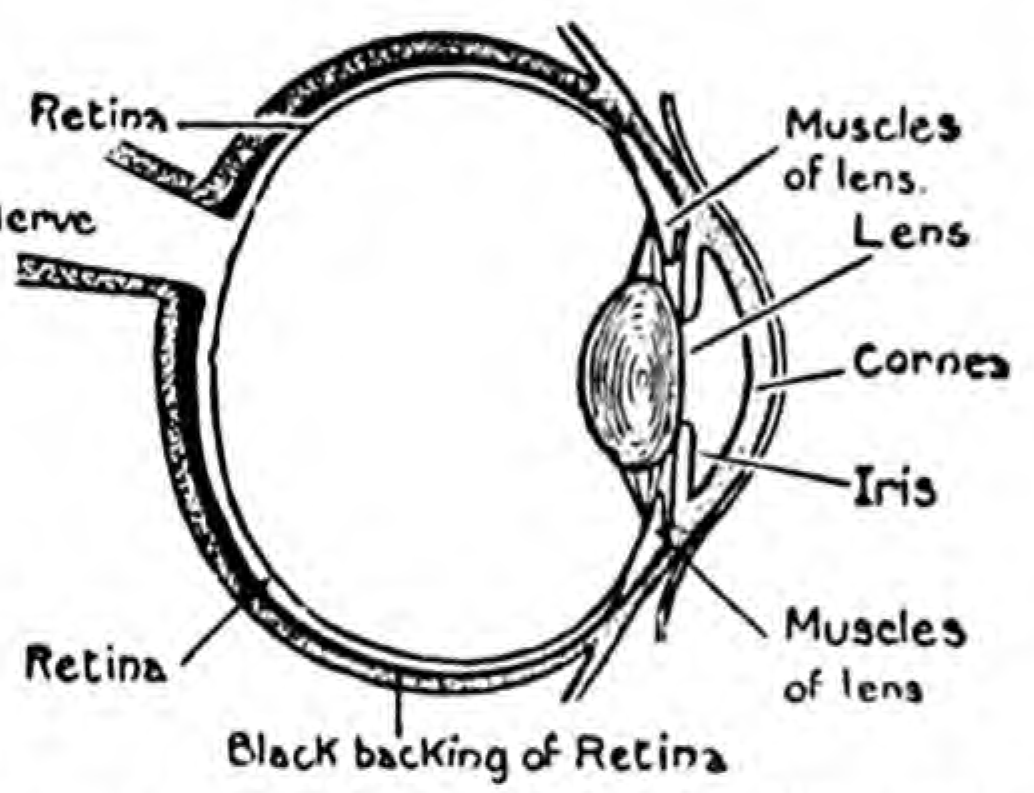


FIG. 43.—*How an eye looks when cut across* (*it is the right eye, cut across horizontally*).

Then, of course, the amount of light that gets through on to the film is important. To deal with this, cameras have what is called an iris diaphragm. This consists of a set of little metal pieces which can all be moved at once to make the hole or *aperture*, through which light gets into the camera, bigger or smaller. Then there is the shutter, which keeps the light out except when you want to take a picture: and finally everything is enclosed in a box, strong enough to protect the parts inside and to ensure that they keep the right distance from each other. The box is made black inside to prevent any light being reflected from its walls, which would fog the picture on the film.

In an eye, you find very similar parts. Outside is a spherical box, of strong white material, but with a delicate black membrane inside to prevent light from being reflected inside the eyeball. The material of the box is not so strong as the box of a camera, so, to give it more firm-

ness, it is filled with a rather watery jelly, which keeps its walls expanded. Lining all the inside of the box at the back is what corresponds to the film in a camera—a living membrane which is sensitive to light. This is called the *retina*. Then there is a lens, very like the lens in a camera, but all made by living substance. The main difference is that it is right inside the eye, the front of the eye being covered by a window of horny transparent material. Then, just as in the camera, there is an arrangement for controlling the amount of light that gets in. The black pupil of your eye is the actual hole through which light enters (it is called pupil from the Latin word *pupilla*, which means a little doll; because if you look closely into someone else's eye, you see a reflection of yourself, like a tiny doll, right in that black space).

When you look at the pupil, you are looking right into the inside of the eye; but you cannot see the back of the eye because there is so little light inside. In the same sort of way, if you are looking at the front of a house on a sunny day, an open window will look dark because there is so little light inside the room compared with the light outside. For looking at the back of the eye, doctors use an instrument which sends a beam of light through the pupil. Then they can see the retina, which is a deep red colour.

The coloured part round the pupil is the diaphragm for controlling the amount of light. It is called the *iris*, and the iris diaphragm of the camera is named after it, though it works in rather a different way. If you look at your eyes in a mirror in a dim light, you will see that the pupils are big. Then light a match or shine an electric torch on your eyes; you will find that the pupil at once gets smaller. This is caused by the muscles in the iris,

which can either squeeze the iris down to make the pupil smaller, or else pull it back to make the pupil larger. These muscles act according to the amount of light. When too much light reaches the retina, it sends a message up its nerve to the brain, and the brain sends a message down another nerve to the muscles which make the pupil smaller. A cat has a differently shaped pupil. In very dim light it is round like ours, but in bright light it is a narrow up-and-down slit. In dim light a cat's pupil is much bigger than ours ever gets: as cats hunt by night, they need to be able to get as much light as possible into their eyes.

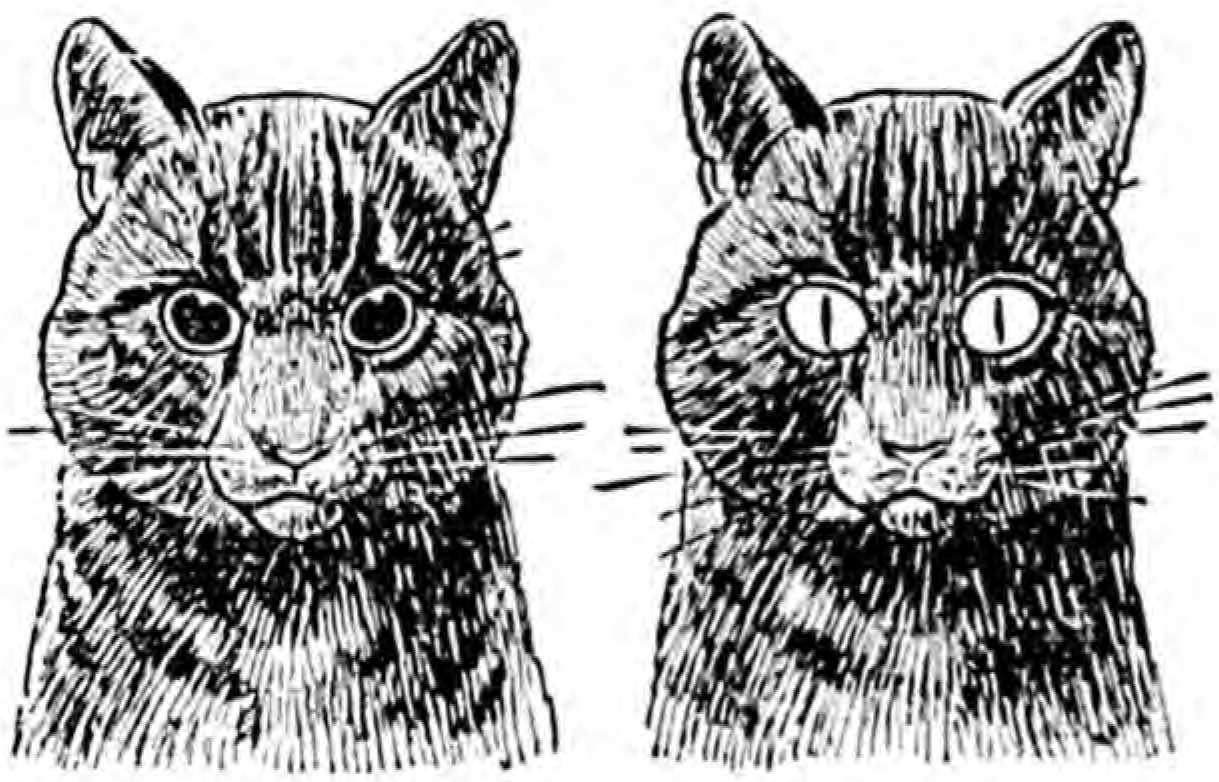


Fig. 44.—*Why a cat sees in the dark better than we can. In the dark, the pupils of its eyes can expand very wide. In the light, they shrink to mere slits.*

Besides all this, there are the focussing arrangements to think of. If you are to see properly, the lens must always give a sharp image on the retina. This is not easy, because when distant things give a sharp image, near things will be out of focus, and *vice versa*. If you take a glass lens and arrange it so as to give a clear image of something far away, you will find that the image of things that are closer is all blurred. If you then want to get a sharp image of something closer, you will find that there are two ways of doing it. Either you can move the lens further away from where the image is to be; or else you can put a different lens at the same distance. The lens of your eye cannot change its position; it is always at the

same distance from your retina, so that moving the lens is no good: something must be done to the shape of the lens.

The lenses which are used to make an image in a camera, like the lens in your eye, are curved outwards on both sides (or *biconvex*: convex means curved outwards, and bi- is from the Latin word for twice—"both sides convex"). But some bulge more than others. If you have two or three glass lenses of this sort and place them one after another at the same distance from a white piece of card, you will find that the fatter and more bulgy the lens, the closer is the object of which it will make a clear image.

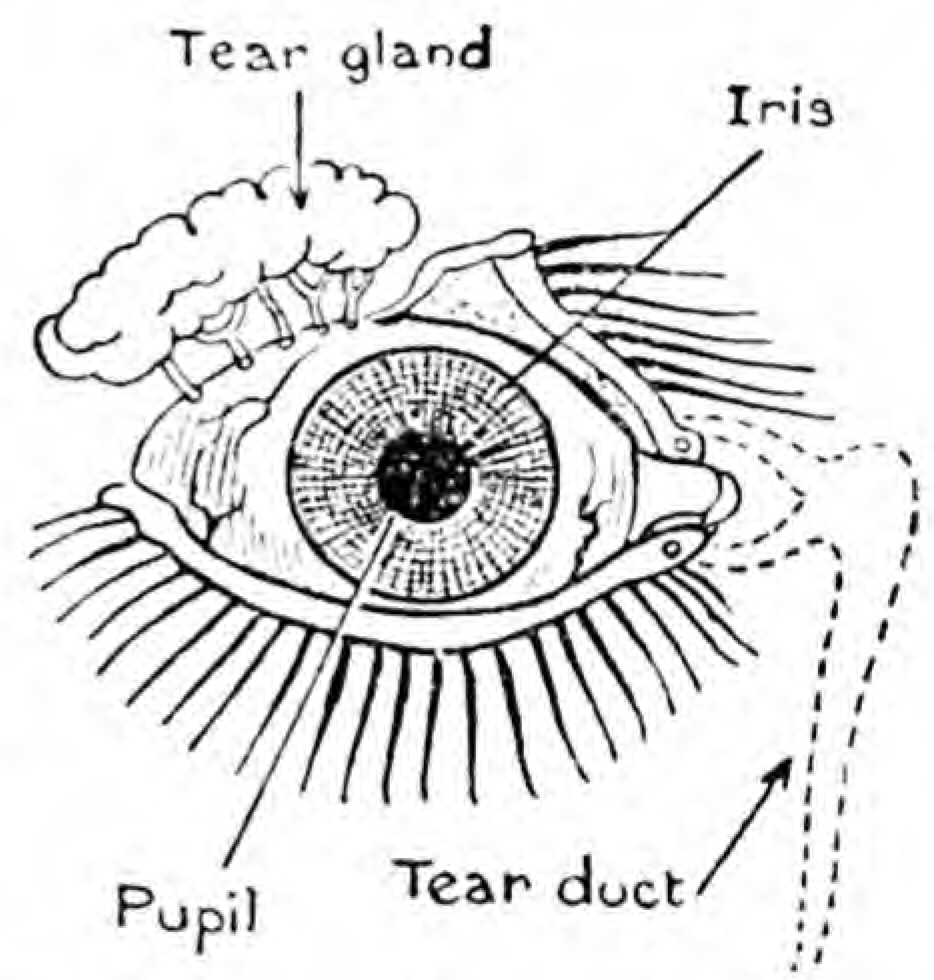


FIG. 45.—*How the surface of our eyes is kept clean and prevented from drying up. Moisture secreted by the tear-glands trickles across the eye, and is led away down little pipes into the inside of the nose.*

Of course, if you could make the lens actually change its shape, this would do. You cannot do this with glass lenses; but the lens of your eye is made of an elastic material, and by a rather complicated arrangement, it is made to bulge out when certain muscles round the edge of your iris contract. You know how when you try to look at something very close, you have a sense of effort in your eye: this is because you are contracting those muscles as hard as possible. So in focussing for near objects, a camera works in one way, and your eye in another.

Then your eyelids are for keeping light out when it is not wanted. There are also arrangements for keeping the

surface of your eyes clean and free from dust. Those are your tear-glands. Most people think they only have tears when they cry. But, as a matter of fact, the tear-glands are all the time secreting just a little liquid, and this drains across the front of your eyes. It is spread over the surface by your blinking, and then drains out down narrow tubes into your nose. When you cry, the nerves to the glands make them secrete much more, and some of the secretion overflows: that is what makes regular tears.

The Brain helps in Seeing

There is one very interesting thing about the way you see things. The image made by a biconvex lens is upside-down, as you will have seen in your experiment with glass lenses. The same is true of the image made by your lens on the retina of your eye. Why, then, do we not see things upside-down? The answer is that the real *sensation* of seeing is not the concern of the eye, but of the brain. The eye is just an instrument, like a camera, except that it happens to be part of your body. It is connected with the brain by a big sensory nerve, which you can easily see in an ox's eye. Every part of the sensitive retina of the eye is joined to fibres of the eye-nerve. And when light falls on one particular part of the retina, messages are sent to the brain along its particular fibres. You never see the actual image on your retina. This could only be done by somebody from outside who could look at the back of your eye. What your brain does is to deal with the messages in the eye-nerve fibres; in some way we do not yet understand, these messages give the brain the sensation of sight, and then we see a picture.

Perhaps you will understand this better by thinking about the telephone. When you listen to somebody talk-

ing over the telephone, you do not hear his actual voice. In the telephone into which he is talking, his voice is translated, so to speak, into electrical messages which run along the wire, and are translated back again into sound in the telephone at which you are listening. What you hear is a "sound-picture" of his voice. This is different in one important way from what happens in seeing. In the telephone, what comes out of the telephone is actual sound, as like as possible to the original sound of what went into the instrument at the other end of the wire. But in seeing, what goes on in your brain is quite different from what goes on in your retina: there is no actual image inside your brain as there is at the back of your eye. However, what is happening in the telephone wire will perhaps help you to understand what happens in your eye-nerve. In both cases the original happening, in one case a sound and in the other case a picture, has to be translated into a sort of code message; at your end of the telephone wire this has to be translated back again into sound, while at the brain end of the eye-nerve the message has to be translated again into something to do with sight.

To come back to the image on our retina and the way we see things with the help of our brain: while we are babies, we learn by touching and handling things that a particular message from the eye to the brain corresponds to a particular thing outside ourselves, and so we see things "right way up." The way up of the image on the retina has really nothing to do with the seeing process that goes on in our brain.

In any case, the image on the back of your eye is flat (or rather on a curved surface); and yet what you see looks solid. It is your brain which enables you to understand what this flat image means, and to make a solid picture out

of it. It is easy to show that it is the brain which does this. Look at the picture on this page (Fig. 46). It is actually just an arrangement of twelve straight lines, all on the flat. But a transparent cube, like a glass box, if seen a little from above or below, would make a flat image of this sort on your retina; and when you look at it, you will see it as if it actually were a cube. However, if you look steadily at it, you will find that for a certain time it will

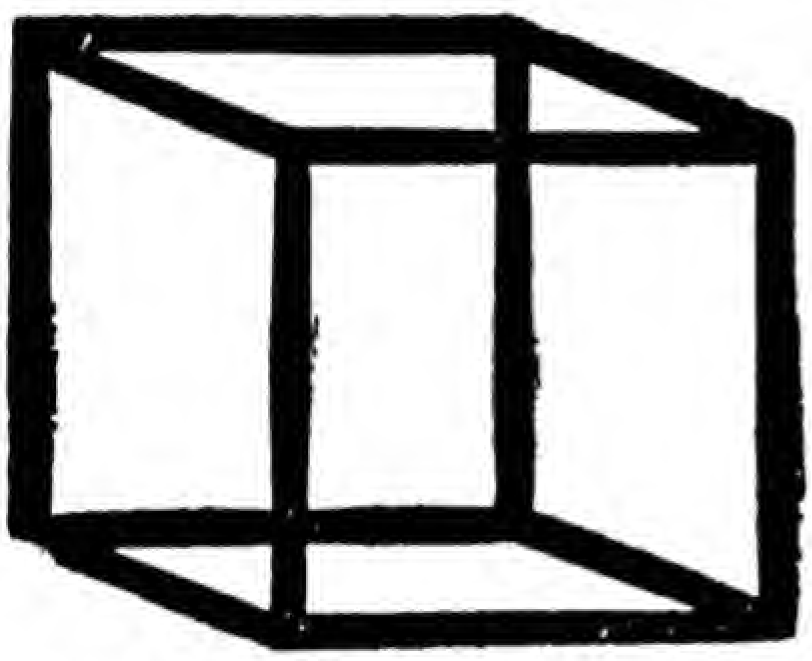


FIG. 46.—*Our brains judge the meaning of the things we see. These black lines look like the picture of a hollow cube. But is the cube facing up and to the left, or down and to the right?*

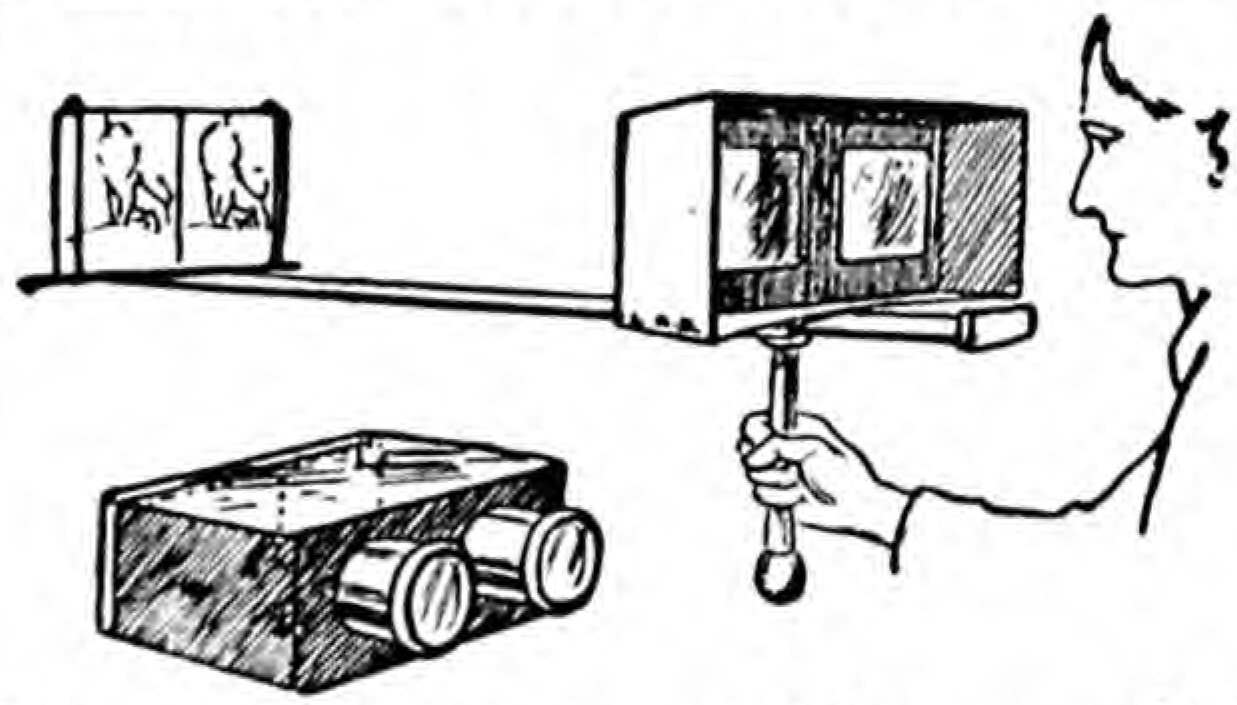


FIG. 47.—*Stereoscopes. The one which the boy is holding is focussed by moving the part with the lenses in it. In the other one, the eye-pieces screw in and out.*

look like a cube seen from above and to the right, and then suddenly will seem to change into a cube seen from below and to the left. The flat image can be understood or interpreted in both these ways. When your brain gets tired of one way, it tries the other.

The ordinary stereoscope (which means something which sees solid) also proves that it is your brain which uses the flat images in your eyes to give you a solid picture. The way a stereoscope works is this. Two photographs of the same scene are taken, but from two different positions a short distance apart. They are generally taken by a double camera, with two separate lenses and two sets

of sensitive plates or films. The pictures are then put side by side in the stereoscope, which is so arranged that your left eye can only see the left-hand picture, your right only the right-hand picture. If the stereoscope is properly adjusted, you will not see two pictures, but one; and it will not look flat like a photograph, but will seem to stand out solid as in reality. Your brain has combined the two different flat images into a single solid picture.

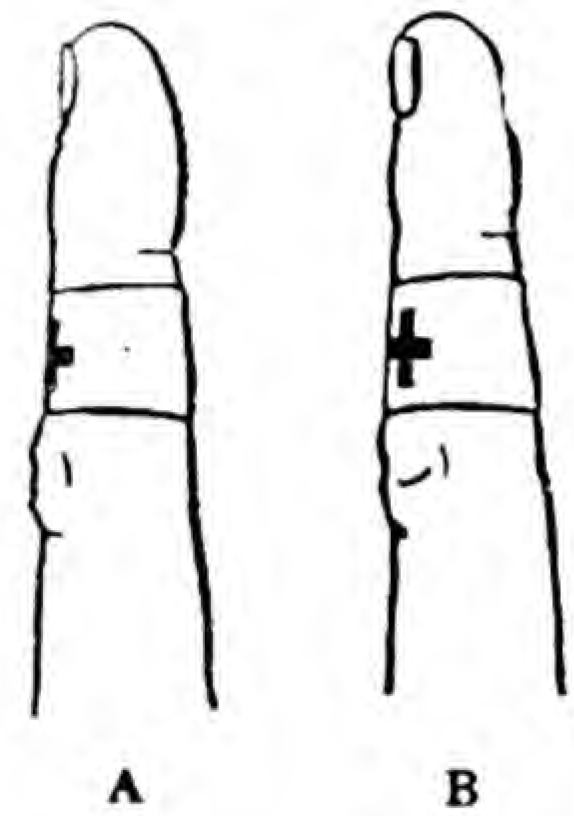


FIG. 48.—*The left forefinger, as seen from about 8 inches (A) by the right eye, (B) by the left eye. A piece of paper with a cross drawn on it has been stuck on the finger.*

As a matter of fact, this is why using two eyes makes the things you see look more solid, and helps you to judge distances more easily. Even with one eye you get some sense of solidity and distance: this is because you have learnt by experience that the lights and shadows on solid things are quite different from those on flat things. The extra solidity which comes from using two eyes is due to their acting like a stereoscope. As your eyes are a couple of inches apart, they make different images of the same object. You can easily see this by holding up your right forefinger about 8 inches from your nose and looking at it first with one eye only and then with the other. If you hold it so that with your left eye you can see the fingernail exactly in side view, you will find that with your right eye you can see a good deal of the surface of the nail. Your two eyes make two separate and slightly different flat images on their retinas, and send up two slightly different sets of messages to your brain. The brain combines them both into a single solid-looking picture.

We may mention one more experiment with sight here, as it is rather interesting. If you hold the book in one hand about a foot away from your face, then close your right eye and with your left look straight at the cross in Fig. 49,

FIG. 49.

and then slowly bring the book closer, you will find that when it is about 8 inches away, the circle will disappear, and then reappear again when you bring the book still closer.

The circle disappears because its image has fallen on what is called the blind spot. This is where the eye-nerve leaves the eyeball; and just here there is a gap in the retina through which the big nerve passes. Both eyes have a blind spot; but in the compound picture made by the brain, the gap left by the blind spot of one eye is filled up from the image given by the other eye.

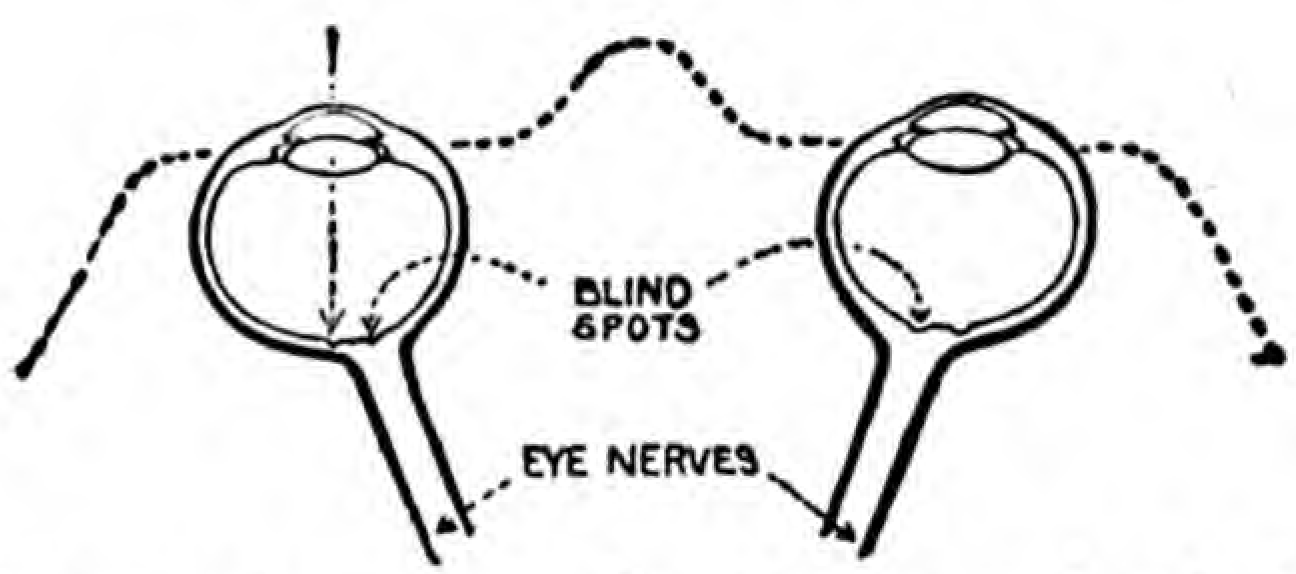


FIG. 49A.—*How the eyes are placed in the head.*

SEEING COLOURS

The retina is more complicated than an ordinary photograph film, which only gives a black-and-white picture. It is like the new colour-films, which can be made to give pictures in colours. However, a certain proportion of people are born with eyes which are not made to distinguish colours properly. These people are called "colour-blind." People who have the commonest sort of colour-blindness cannot tell red from green. This red-green

colour-blindness is not at all uncommon among men and boys—about one in every twenty-five has it: but it is over ten times as rare in women and girls. This curious difference between men and women depends on the machinery of heredity, but it would take too long to explain it here. It would be dangerous for people who have this sort of colour-blindness to take on certain kinds of work, such as being an engine-driver, and candidates for such posts must have their eyes very carefully tested.

There is another very wonderful thing about our eyes, and that is how they can adjust themselves to changes in the amount of light. We have seen that up to a point they can do this by making the pupil bigger or smaller. However, when the light grows very faint this will no longer help. With a camera, people can get over this difficulty by using specially sensitive films. Something of the sort happens in our eyes. In our retina we really have not one kind of sensitive film, but two. One works well in bright light, the other in weak light. You know how when you go into a darkened room, it seems pitch black at first, but after a time you begin to be able to see a little. This is because the part of your retina that works in very dim light has come into action. This part of our retina cannot see colours; it is only sensitive to black and white. That is why we can only see colours in a fairly good light. At night, or in a darkened room, we can only see things in black and white and different shades of grey.

It is interesting that very few animals seem able to see colours. We can, and monkeys, and birds, and certainly some insects such as bees and butterflies. But most familiar animals like dogs and cats and horses seem, according to the results of experiments, only to be able to see in black and white.

Then there are a great many animals which have eyes made to give a black-and-white image, but the eyes are so simple in construction that the image is a very poor one—just as if you had in your camera a badly-made lens with no focussing arrangements. The result is that they get only a very blurred picture.

If you go up to a crab on the sand, for instance, the crab, it seems, sees you as a dark moving shape, without being able to distinguish any details. Big moving shapes frighten him, and so he leans back and nips with his claws.

Finally, do not let us forget that very many animals have no eyes at all. Earthworms, for instance, and sea-anemones, and creatures like ciliates (Part I, Chapter I). But even these may be sensitive to light. If you go out on to a lawn on a warm moist night, you will probably see plenty of earthworms about. And if you flash a bright light from an electric torch on to their front end, you will find that they are very sensitive to it, and squirm about, trying to get away from it into the darkness. The worm has tiny organs in its skin which are sensitive to light: but as it has no lens or other arrangements for making an image, it can only tell light from darkness, without getting any proper picture of what is going on outside it.

Although the construction of our bodies is so wonderful, it is not always perfect. Some people, without any fault of their own, are born cripples or deaf or with some other kind of disease or defect. This is true of our eyes too. For one thing, the eyeball is not always the right shape and size for the lens. In an eye of the right shape, the image which the lens makes of distant objects is sharply focussed on the retina. But if your eyeball is shorter

than usual, the image on your retina is blurred, even when the lens has changed its shape as much as possible. In the same way, if you use a glass lens to make a sharp image on a piece of paper, and then move the paper forward a little, the image will lose its sharpness.

An eye made like this is long-sighted. It can see distant things without any effort, but can never get a sharp picture of things that are quite close. The trouble can be overcome, however, by using spectacles. The lenses of these must be convex.

Eyes with eyeballs which are too long will of course give just the opposite results. They will be short-sighted, and will need spectacles with concave lenses. If you have some concave and convex glass lenses, you can make an experiment to show this. First make a sharp image of something, like the window or a lamp, on a piece of paper. Then make it blurred by moving the paper further away, as we described just now. This is like what happens in a short-sighted eye. However, you can bring back the sharpness of the image by putting a concave lens of the right shape close to the original lens. You can also arrange an experiment to show how convex lenses will help with long sight.

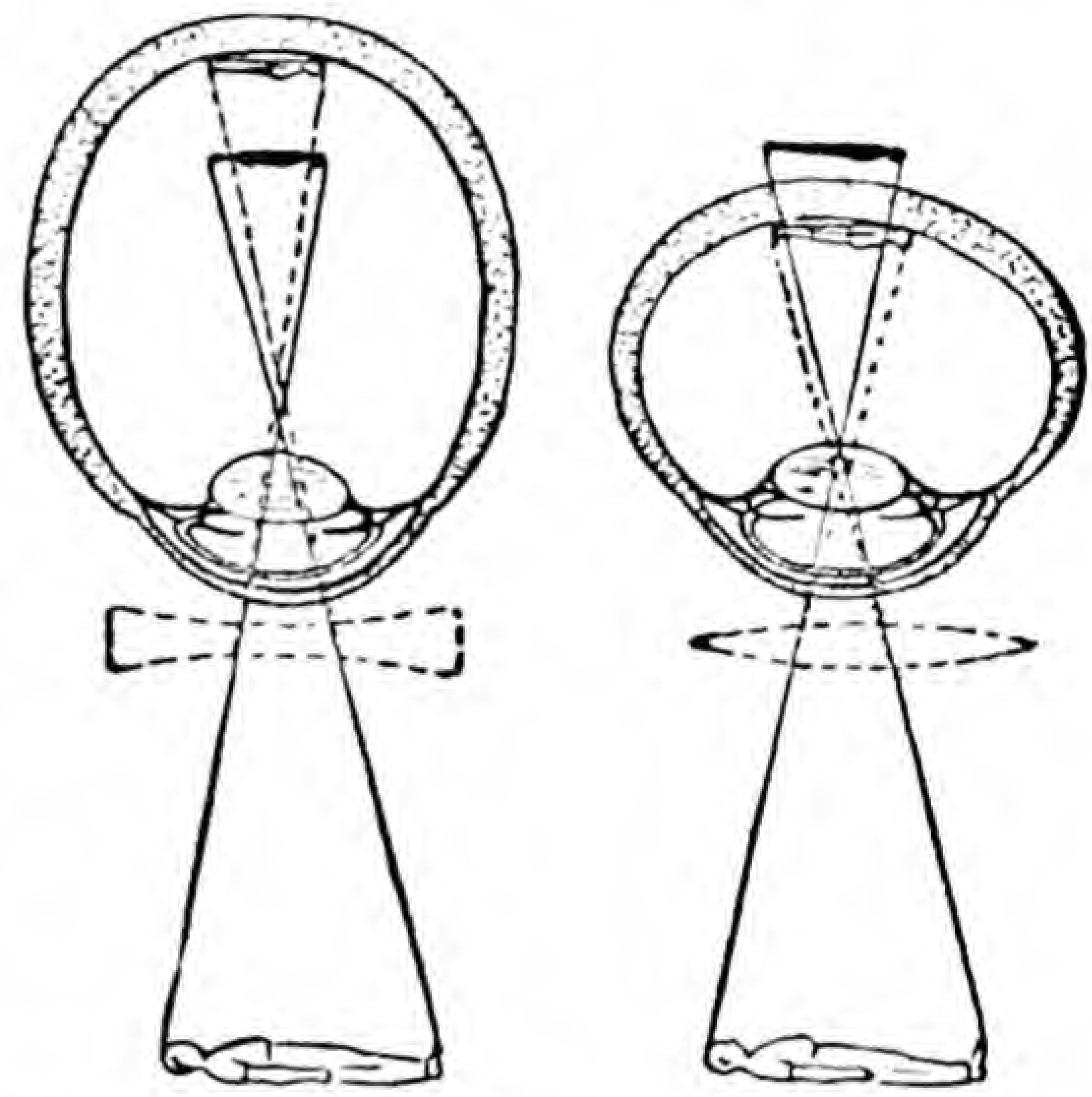


FIG. 50.—*A diagram to show the cause and cure of short sight (left) and long sight (right). Short sight can be remedied by spectacles with biconcave lenses, long sight by spectacles with biconvex lenses.*

However, the commonest eye-trouble has to do with the shape of the *cornea*, as the transparent window of the

eye is called. If a sharp image is to be produced, the shape of the cornea ought to be part of a perfect sphere, so that its curve is the same in all directions. Sometimes, however, it is curved unequally. For instance, its up-and-down curve may bulge more than its side-to-side curve. When this happens, the image on the retina is not equally sharp in all directions. So the muscles of your lens are all the time making an effort to sharpen the image, and the result after a time is tiredness and headaches. This trouble is called *astigmatism*. It too can be set right by glasses. It is very easy to see whether you have astigmatism. Look at the test and slowly turn the book round. If each set of lines first looks sharper and then rather blurred, and so on, you have astigmatism and ought to be wearing glasses.

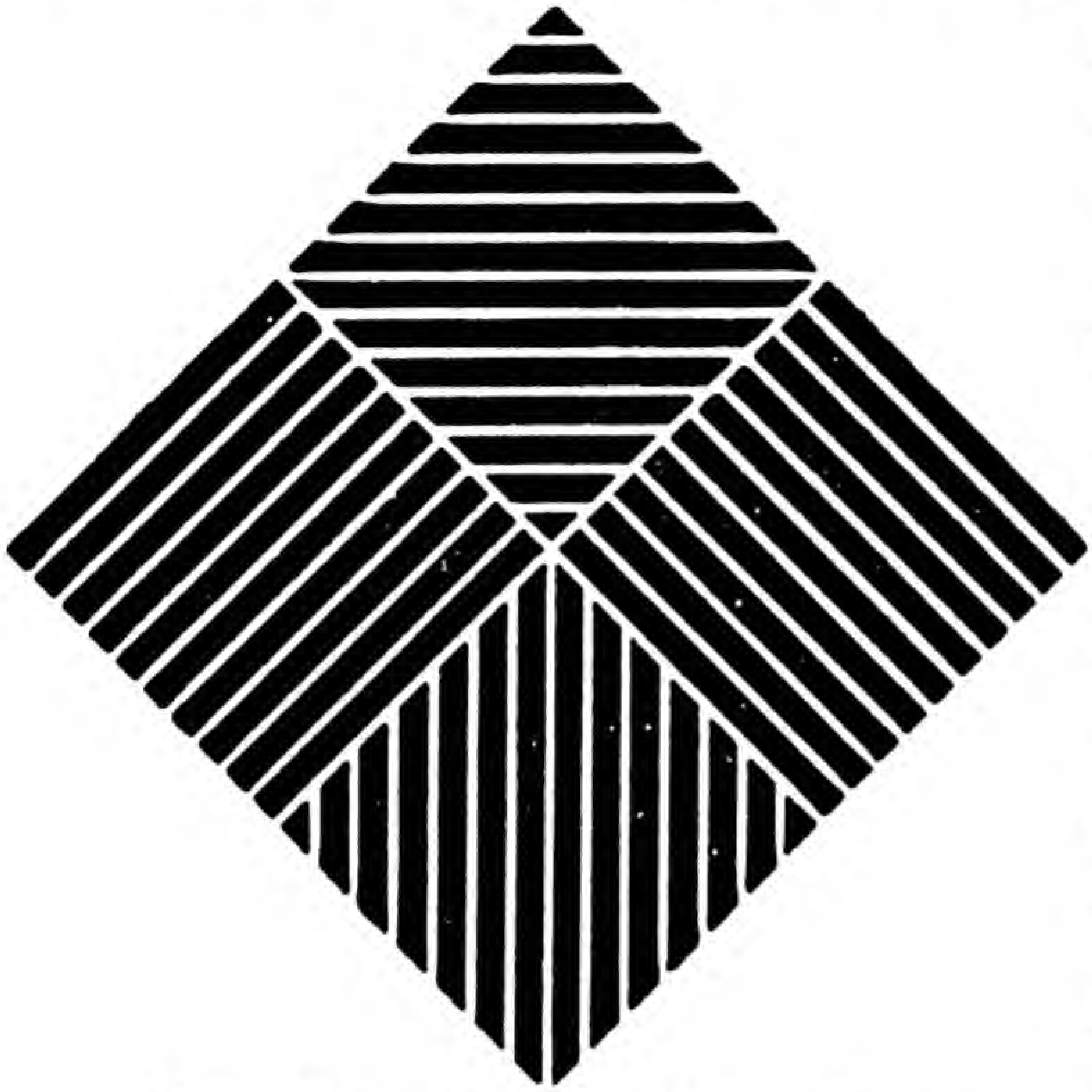


FIG. 50A.—*Test for Astigmatism.*

HEARING, SMELLING, AND TASTING

You will be surprised to learn that many fewer animals can hear than can see. Backboned animals can all hear, though fish hear very poorly. But, apart from them, it seems that no creatures except a few insects can hear at all. It is interesting, by the way, that some grasshoppers,

namely those with long feelers, have their "ears" in their legs. You can see the opening of this hearing organ on the inside of the first thin joint of the leg. The grasshoppers with short feelers also have "ears," but these are on either side of their bodies, as shown in the picture.

Sight deals with light, which can travel through empty space. Hearing deals with vibrations, which cannot travel across empty space. This can be shown by means of the old experiment of putting an electric bell, driven electrically or by clockwork, and suspended by thin rubber threads, in a jar from which the air is then pumped out. The sound will grow fainter and fainter and at last fade out altogether, to grow louder again if you let air in once more. Of course, if the bell is put on the bottom of the jar, instead of being hung by thin threads which conduct sound badly, the sound will pass through the jar and its stand to the table, and from the table to the air in the room.

What we generally call "ears" are really only ear-trumpets—arrangements for catching sound. Many animals have much better ear-trumpets than we have. A donkey, for instance, has a very big ear-trumpet, and can turn it in different directions, according to where the sound is coming from. The true ear that does the hearing, both with us and with the donkey, is right inside the bones of the skull. There is an in-

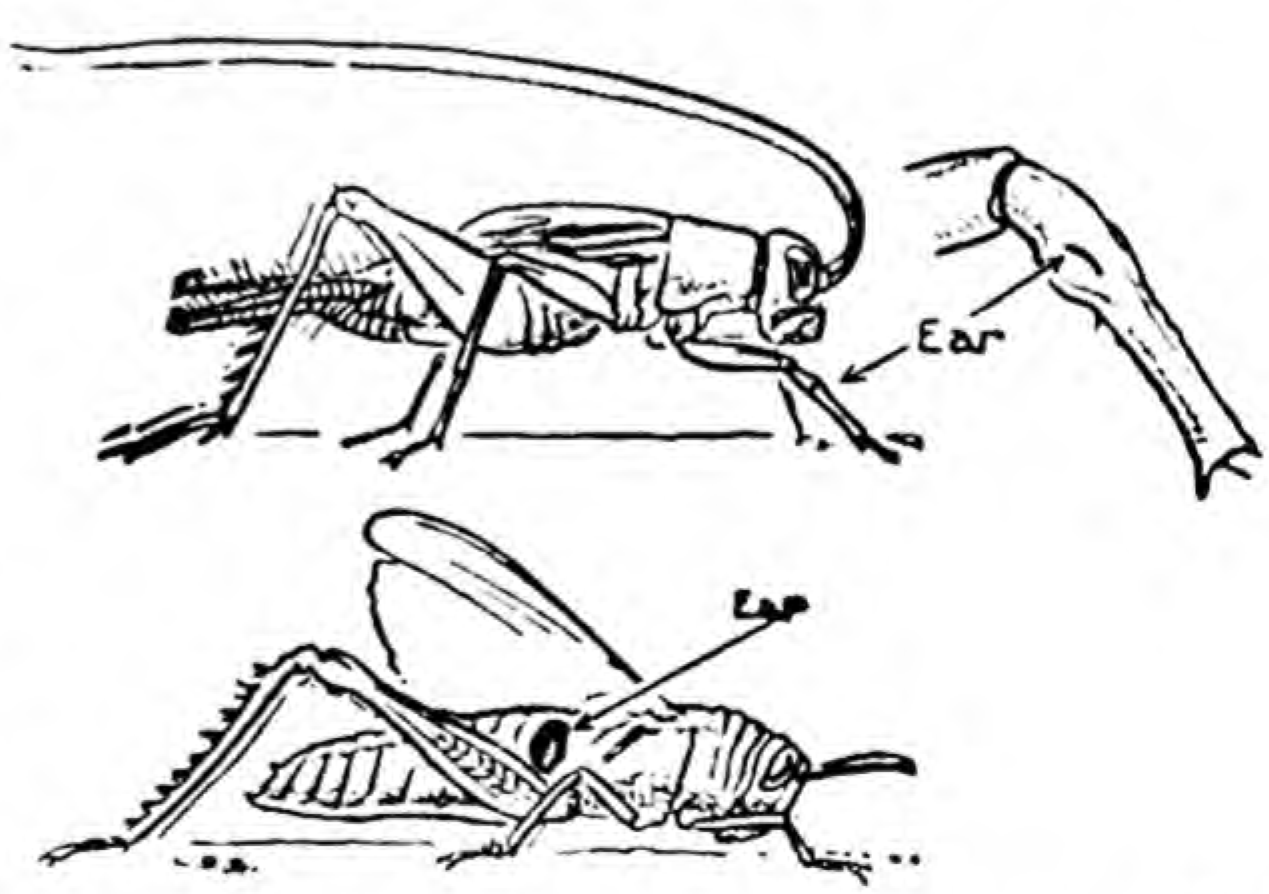


FIG. 51.—*Some insects have ears. The house cricket (above) has its ears in its front legs. The locust (below) has its ears on the side of the body. (The cricket is about ½ inch long, the locust about 2½ inches.)*

genious arrangement for getting the vibrations of the air to it. At the bottom of the trumpet part of the ear is the ear-drum, which is a tough skin or membrane tightly stretched across the end of a tube, like the skin of a drum. It vibrates when air-vibrations hit it. Fastened to its inside is one end of a chain of tiny bones, and the other end of the chain fits into another much smaller drum, which is part of the actual organ of hearing.

When somebody talks to you, his voice makes the air vibrate, this makes the drums of your ears vibrate, and the little chain of bones takes the vibrations across to the hearing part of the ear inside. This sends messages up a nerve to the brain, and then you hear the sounds.

Smell and taste are the next senses to consider. Taste is concerned with various substances that dissolve out of your food as it slips over your tongue, in which the organs of taste are. Smell, on the other hand, deals with tiny particles of matter in the air, which get dissolved in the film of moisture on the lining of your nose, and there act on the sensitive smell-organs which then send messages to your brain.

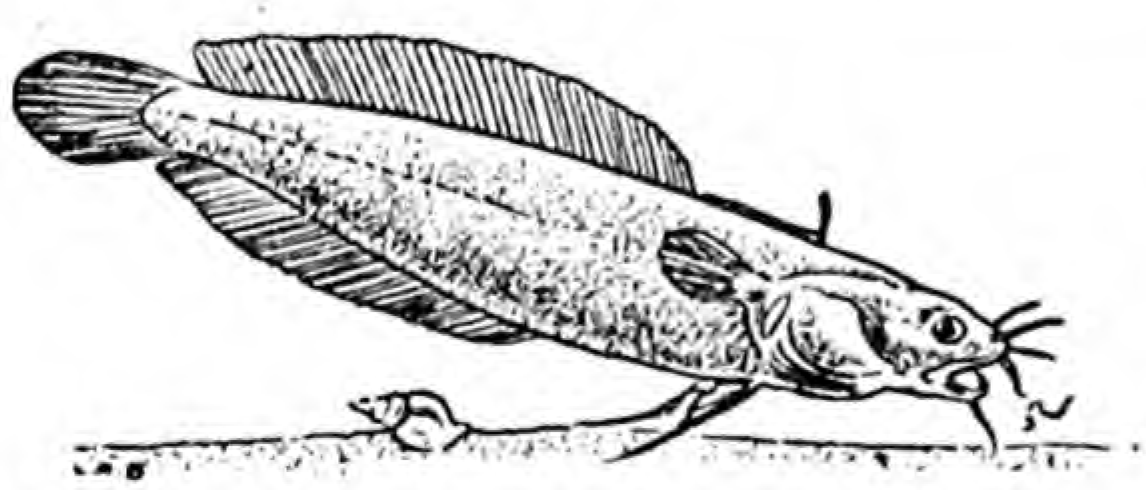


Fig. 52.—*Tasting outside the mouth. The rockling can taste things with its feelers and with two of its fins as well as with the inside of its mouth.*

As a matter of fact, much of what we usually call taste is really smell: particles from the food get into the air in our mouths, and are snuffed up into our noses. The reason you cannot taste your food properly when you have a heavy cold is that your nose is out of action: the real taste-organs are still working, but they can only tell you if things are sweet or bitter, salty or sour. It is amusing

to get someone to shut his eyes and hold his nose tight, and then see if he can tell apple from turnip, or bread from cake. Some fish, like the catfish (which you can see in the aquarium at the London Zoo), have things which look like whiskers sticking out and down from their mouths. These are not only feelers, but also tasters. They have taste-organs on them, so the fish, by using these whiskers, can taste things in the mud on the bottom and judge if they are good before taking them into its mouth. Other kinds of fish, like the one in the picture, can even taste with their front fins.

Have you ever thought how small your nose is in comparison with a dog's, for instance, or a horse's? This is because we depend chiefly on sight and hearing, and smell is not very important to us. But a wild dog or fox has to hunt by smell, and a wild horse or deer has to be able to smell its enemies at a distance; so smell is the most important of all the senses to these animals. In the Arctic winter foxes have been known to smell the bait in a trap five miles away. If you look at the skull of a dog or rabbit or sheep which has been split in two, you will see a big space in the nose filled with delicate scrolls of bone. When the animal was alive, these were covered with a moist membrane with the smell sense-organs in it. With all this big surface to smell with, it is no wonder that these animals are so sensitive to the faintest smells.

FIG. 53.—*A man has a much poorer sense of smell than a dog, but a much better brain. The inside of the nose is drawn black, the space taken up by the brain is dotted.*

Touch, Temperature, and Pain

All the senses we have spoken of so far are dealt with by special organs in one place. But the rest of our information about the world outside is got from senses whose organs are scattered all over the surface of the body. These are touch, heat and cold, and pain. All over you, embedded in your skin, are microscopic organs which are sensitive to pressure: it is by means of these that you know when something is touching you, and how hard it is pressing on you. On some parts of your body, like your finger-tips or your tongue, where you need a delicate sense of touch, these little organs are crowded together. But in other parts, like your upper arm, or the middle of your back, they are far apart, and there your touch-sense is much less accurate. You can test this with a pair of compasses (to prevent accidents you can put very small sealing-wax tips on the points). If the points are very close together, you will only feel them as one point. Then blindfold someone, and try on different parts of his body what distance apart the points must be for him (or her) to feel them as two and not one. You will find that on his finger-tips he can tell there are two points when they are only a tenth of an inch apart, but on the small of the back he will still only feel one point even when he is really being touched by both points and they are over an inch apart.

In the same sort of way, you cannot feel heat and cold and pain everywhere: the organs for those senses are scattered about over the surface of the body, and there is a definite distance between one organ and the next. If you mark out a square on the back of your hand with ink and then hunt about in it with the blunt end of a hot needle,

you will find that at some places you will feel its heat very well, but at others hardly at all. Mark these "heat spots" with ink, and then try again with a cold needle. Now you will find the "cold spots" which have in them the sense-organs sensitive to cold, and if you mark these with different-coloured ink, you will see that they are not in the same places as the heat spots. Finally, you can try for "pain spots" with the sharp end of the needle. These are the places where even a small prick of the needle feels very painful: in between them are places where you feel much less pain.

There is one curious thing about your pain sense. Your stomach and intestines can only feel pain when they are stretched too much. Pricking or cutting them does not cause pain. This reminds us that our senses, like the rest of us, are suited to the work they have to do. Ordinarily our intestines are not liable to be cut, except in an accident bad enough to kill one anyhow, or in an operation; so nature has not troubled about making us feel pain from that sort of thing. But they often get stretched—for instance, when we eat too much, or when we eat too quickly, so that gas is formed inside them—and the resulting stomach-ache is a reminder to us that something is wrong, and a warning not to act in the same way again.

Pain, in fact, has a use, and the use is to serve as a warning signal that something is wrong. But it is a very rough-and-ready use, and often we should be better off without pain. Some of the greatest benefactors of the human race have been the doctors and scientists who have discovered how to get rid of unnecessary pain by means of what are called *anæsthetics* (the word comes from two Greek words meaning "without feeling"). The most im-

portant anæsthetic is chloroform, the use of which was first discovered by Sir James Simpson, a Scottish doctor, less than a century ago, in 1847. The patient is made to breathe chloroform vapour mixed with air. This dissolves in the blood, and when it reaches the brain and spinal cord it does something we do not yet fully understand, which not only prevents them from sending on messages about things that usually would be painful, but stops the patient having any feeling at all. After breathing a mixture of air and chloroform for a little time a man becomes quite unconscious. If he is given too much chloroform, the brain can no longer send out the messages which make the man breathe, and he dies; if he is given too little chloroform, he will still feel something; but if he is given just the right amount, it stops him feeling without preventing him from going on breathing. So if someone has to have his leg cut off, or any other severe operation, a surgeon can now do it painlessly with the aid of anæsthetics, while before the time of Sir James Simpson, the man would either have had to die, or else undergo terrible suffering through an operation without anæsthetics.

An anæsthetic which sends you right to sleep, like chloroform, is called a general anæsthetic. Ether is another, and so is "laughing gas," a simple compound of nitrogen and oxygen, which dentists use for short operations, like digging out troublesome teeth. But equally wonderful are what are called local anæsthetics. A local anæsthetic does not send you to sleep. But if it is injected into you at a particular spot, the parts near the injection become incapable of sending pain-messages up the sensory nerves, and so, though the patient stays quite awake and conscious, and can feel pain from anywhere

else, he can feel nothing that goes on in that part of his body. *Novocain* is the best-known local anæsthetic. The commonest use of it is to squirt into your gum when a tooth has to come out. Next time you have to go to the dentist, instead of thinking how unpleasant it is, remember that science, with the discovery of anæsthetics and how to use them, has made it much less unpleasant than it used to be.

The information we get through our senses is usually accurate, but sometimes it deceives us. To show this, an amusing trick is to cross the tips of your first and second fingers as far over as you can, and then (best with your eyes shut) feel something that will go between the tips of the fingers, like a pencil or a bread-pill. Instead of one pencil or one pill, there will seem to be two; or if you try the tip of your nose, it will feel as if you had two noses.

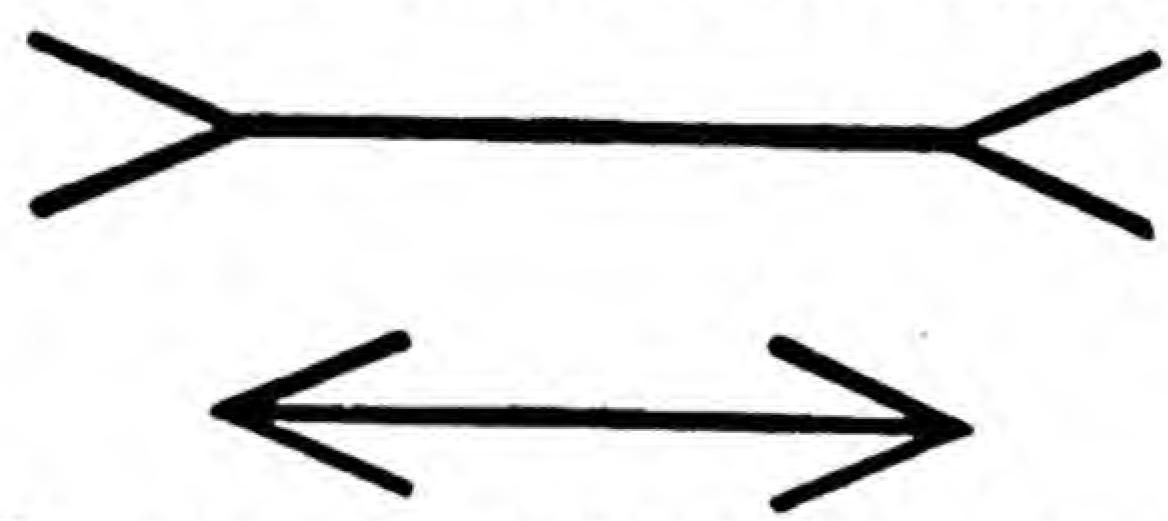


FIG. 54.—*An optical illusion. Say which of the two lines looks longer; and then measure them.*

The explanation of this is not so very difficult. When your fingers are crossed, what you feel between their tips will be touched by that side of your first finger which is nearer your thumb, and by that side of your middle finger which is farthest from your thumb. Now when your fingers are in their proper position, it would need two separate things to touch these parts of your fingers: and your brain is so used to this that when you feel something with crossed fingers, even if you really know that there is only one thing, the part of your brain which deals with touch persists in telling you that two things are there.

Then there are many tricks you can play on the part

of the brain which deals with sight. One very simple way to deceive it is to draw two lines of exactly the same length, and then fit each end of one with a V opening inwards, each end of the other with a V opening outwards. As the picture shows you, the first will look much shorter than the second.

Inside Information

All the senses which we have spoken about so far give us information about things that are happening in the world outside. But it is also important to have information about things that are happening in our own bodies. We will say a little here about these senses. You know where the different parts of your body are and what they are doing. This is so even when they are not touching anything—for instance, if you hold out your hand—and even when your eyes are shut. Then you cannot see your hand, and neither hearing nor smell nor taste nor touch can tell you anything about it; and yet you know just how you are holding it.

This is due to tiny sense-organs, rather like those in your skin which have to do with touch, which are to be found in your muscles, your tendons, and your joints. When a muscle in your arm contracts, for instance, it presses on these sense-organs inside itself, and they send messages to the brain, giving information as to just how much the muscle is pressing on them. When the arm muscles are contracted to a particular extent, it means that the arm must be in a particular position. So the messages from these inside sense-organs give the brain a knowledge of what position the arm is in. This sense is very important, for without it you would never learn to control your movements properly, and, indeed, would not be able even to stand up.

Another inner sense is the sense of balance. The sense-organ for this is in the inside part of the ear, so that your ear really does two quite different things for you. The part of your ear which concerns hearing is inside a spiral tube which looks rather like a snail-shell, and is called the *cochlea* from the Greek word for shell. Besides this, there is a part of the ear which tells you which way up you are, and another which tells you which way your head is turning; both of these help you with your balance.

The part which tells you about your position works with the help of gravity. Inside this part of your ear there are little particles of lime which press on tiny sensitive hairs. The force of gravity will always make the bits of lime press straight downwards. So if your head is tilted, they will press on the hairs at one angle, while if your head is straight, they will press on them at a different angle. The messages from the sensitive hairs are sent to the brain, and give information about your position in regard to gravity. Without this arrangement, you could not tell which way up you were, so long as you kept your eyes shut.

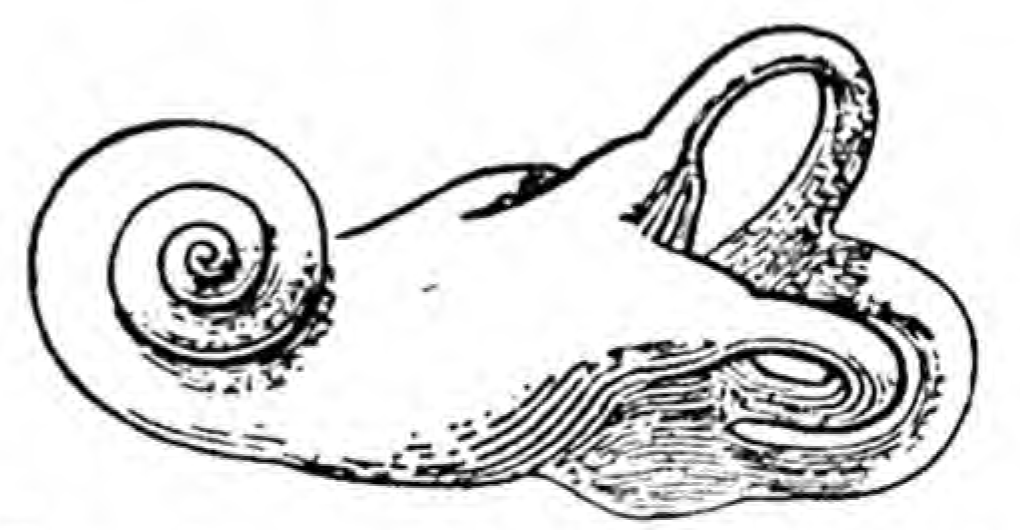


FIG. 55.—*The inside of the ear. The spiral part on the left contains the actual machinery for hearing. On the right is the sense-organ for balance. There are three hollow tubes filled with fluid, each one set at right angles to the other two.*

Then there is the arrangement for telling which way you are moving. This consists, in each ear, of three tubes joined to each other; each is more or less in the shape of a semicircle, and each is set at right angles to the other two. The tubes are filled with fluid, and at their ends are

sensitive hairs. If you move your head sharply from left to right, the fluid in the tube which is horizontal lags behind a little, and presses against the sensitive hairs, which send a message to the brain. By having three sets of tubes at right angles to each other, you ensure that a movement in any direction will be registered on one or other of the sets of sensitive hairs.

If you stand up straight, turn round very fast, and then stop, you know that you will feel giddy. As a matter of fact, you will seem to be turning in the opposite direction. This is because when you stop, the fluid in the horizontal tube goes on spinning for a little, and so presses against the hairs. Your brain is so used to finding out how you move from the way the fluid moves, that when the fluid goes on moving, your brain thinks you must be moving even when you have stopped. You can easily work out why this makes you feel as if you were turning in the opposite direction from what you were actually turning in before you stopped.

Dancers on the stage have to be careful not to get giddy after pirouetting round very quickly. If you watch a dancer carefully, you will see that after twirling round fast she will give a quick jerk of her head in the opposite direction. This will stop the fluid in the horizontal tube from going on spinning, and so she will not get giddy. You can practise this for yourselves; you will find it is not easy to give just the right jerk to your head.

Most people do not know that you can make yourself giddy in another way. If you put your head down on the top of a walking-stick, so that your body is at right angles to your legs, then go round the stick as quickly as possible and then suddenly stop, you will feel as if you were turning over sideways. This is because moving in this way spins

the fluid in the upright canals instead of in the horizontal one. The messages sent to your brain make it feel as if you were falling over sideways. It therefore sends out the sort of messages to your muscles which would be needed if you really were falling sideways, and so you stumble about until the giddiness is over. Sea-sickness and air-sickness, by the way, seem to be largely due to our sense of balance being upset by the continual wobbly movement.

There is a breed of pigeons called tumbler pigeons, which get their name from a funny habit of turning somersaults while they are flying, and there is a breed of mice called waltzers because they find it difficult to go straight from one place to another, but twirl round in circles as they run. Both these kinds of animals are born with something wrong with the semicircular tubes in their ears: this is why they fly or run in a queer way.

The Different Worlds in which Animals Live

We said a little about the absence of eyes or ears in many animals. It is really difficult to imagine the world in which a very simple kind of animal, like a starfish or a sea-anemone or a paramecium, lives. Of course, in one way it is really the same world as the one we live in: but in another way the world of a starfish means that part of the world about which its senses give it knowledge, and that is very different from the world of which a man has knowledge. A starfish has no real eyes or ears. So it can know nothing much of what is happening at a distance from it. It cannot possibly know that stars exist, for instance, or that there is such a thing as music. It can tell the difference between light and darkness, it can feel things which touch it, including currents and vibrations

in the water, it has some sort of chemical sense (like a mixture of taste and smell) to help it find the right kind of food, and it seems to be sensitive to heat and cold. It may be able to feel pain, but probably not very much, for if an arm of a starfish is cut off, with a little bit of the central part of the body attached to it, neither the arm nor the rest of the creature seems to be much worried, and not only will the body grow a new arm, but the single arm will sprout out new arms from the little bit of body attached to it, and after several weeks there will be two starfishes in place of one.

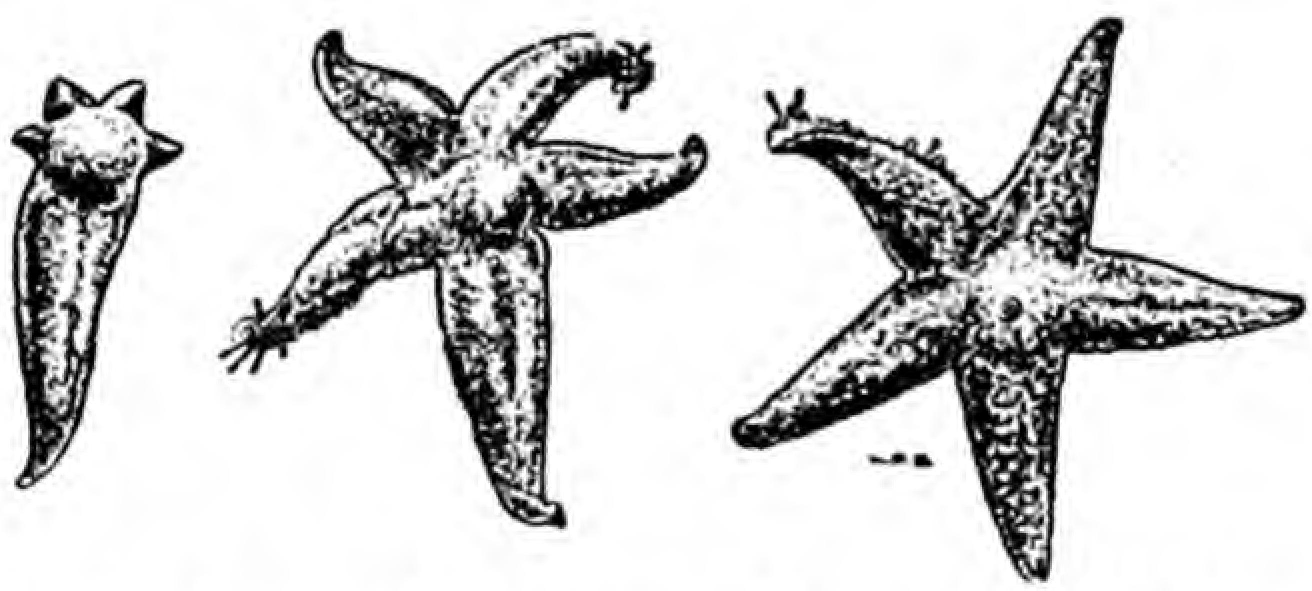


Fig. 56.—*A single starfish arm with a bit of the body growing into a whole new starfish.*

So the starfish's world consists of obstacles it bumps into, occasional smells and tastes of food, a dim knowledge of the change from night to day, the sudden darkness made by fish or boats getting between it and the light, feelings of being too hot or too cold, and perhaps some pain if an enemy gets hold of it. It can hardly even realise there are *things* in the world—all it knows about are a few kinds of *feelings*.

Though the world which a dog or a monkey is able to know about is much richer and more varied, yet there are many things which their senses do not tell them. For instance, they have no sense to tell them whether an electric rail or a cable is actually carrying current or not,

without touching it and perhaps getting killed; they have no sense for knowing whether small quantities of X-rays are hitting them; and no sense for knowing about wireless

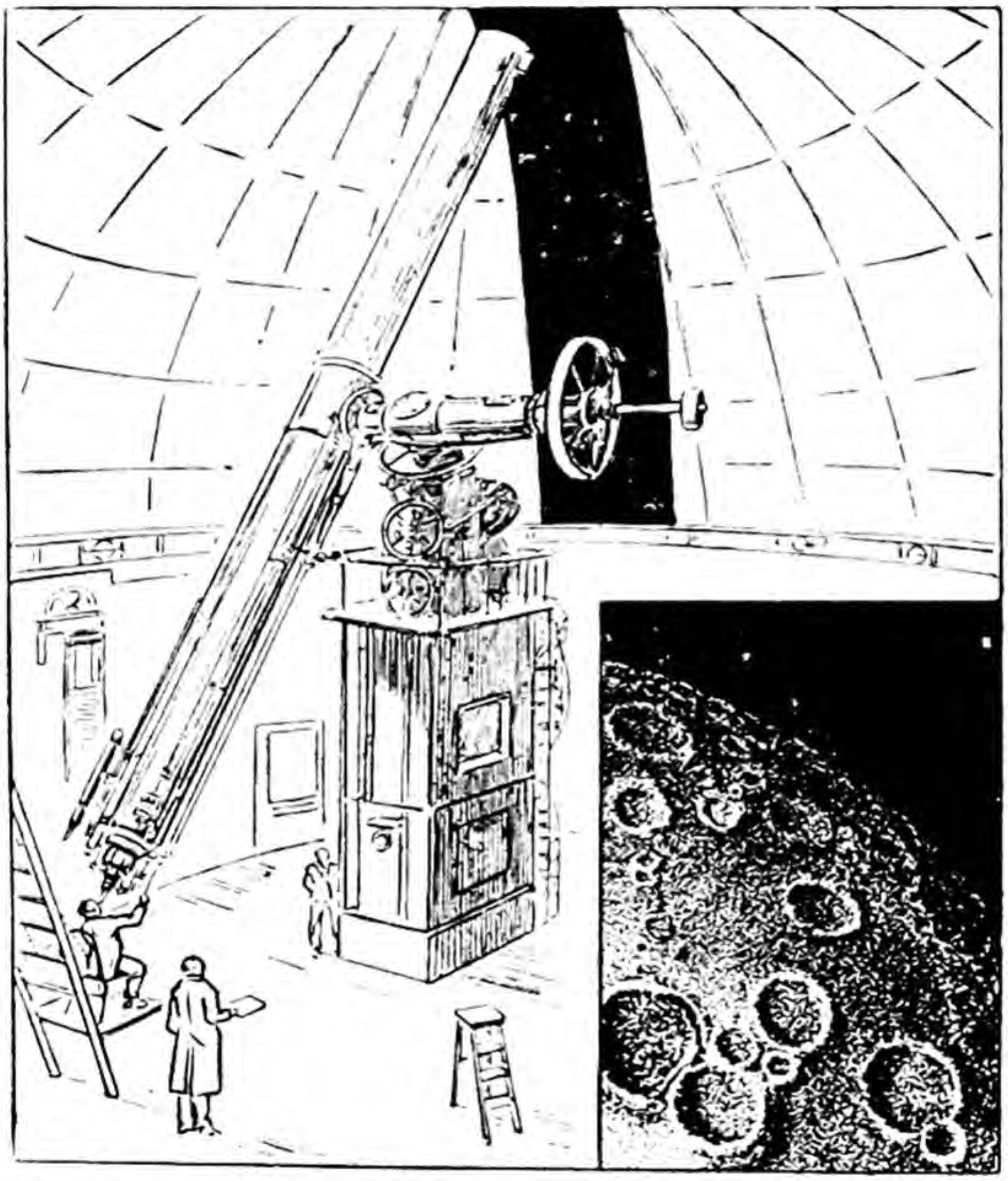


FIG. 57.—*How man adds to the power of his sense-organs. A giant telescope in a modern observatory. Inset, a bit of the moon's surface seen through a telescope. It is seen to be covered with huge craters, which are invisible to the naked eye.*

waves. This is because electric currents and X-rays and wireless waves are so rare in nature that it would be no good having senses to tell whether they were there or not. A dog must have a very different world from ours, because a dog gets its knowledge mainly from smells. A

monkey, on the other hand, is more like a man because it relies mostly on sight and touch.

In his body, a man has only the same set of sense-organs as a monkey. But men have been able to do something which no animal has done. They have invented instruments which act like extra sense-organs, so that they can get all kinds of new knowledge about the world. For instance, a telescope is an arrangement of lenses for making distant things look close. Without telescopes, we should not know that there were mountains on the moon, or moons round some of the planets (Jupiter, for instance, has eight, of which four are very faint), and should never know of the existence of thousands of stars that are too far away to be seen with the naked eye.

Microscopes are arrangements for making small things look big; they make it possible to know about all sorts of things far smaller than even the sharpest-eyed monkey could ever see. There is a picture of a microscope on p. 26 of Book I, And men have made instruments for finding how much electric current is running through a wire, instruments sensitive to wireless waves, instruments which use X-rays to see the inside of people's bodies. There are even instruments so sensitive to heat that they will tell you how much heat is given out by a candle a mile away, or by a star billions of miles away; and others, called spectroscopes, which will tell you, by examining the nature of the light from the stars, the chemical substances of which they are made.

It would take too long to explain here how these instruments work. But the fact that they have been invented means that human beings have provided themselves with a set of artificial sense-organs, and so get much more information about what is happening in the world around

them than any animal can, in just the same way that the tools and machines men have invented make it possible for human beings to have the use of much more power, and to do many more kinds of things than any animal can do with its limbs or jaws or glands. So with the help of the new artificial sense-organs which are all the time being invented, man's world—the part of the universe

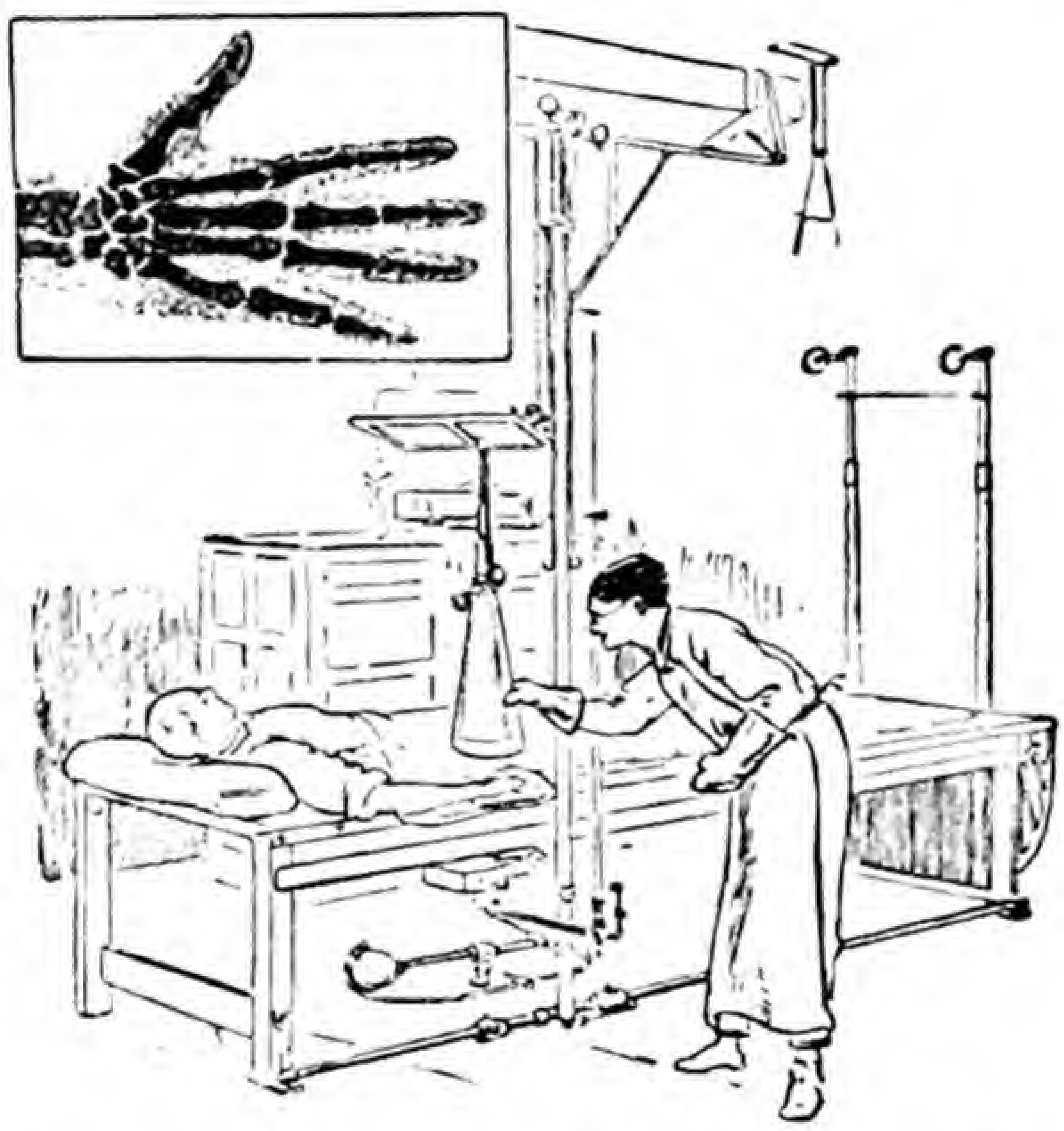


FIG. 58.—*An X-ray apparatus. Inset, the shadow of a human hand as shown by the X-rays. The bones are opaque to X-rays, and look black, while the flesh is more or less transparent.*

which men know of and understand—has been steadily growing since history began.

Let us try to sum up what we have discovered about our bodies in these three chapters. First we have seen that our bodies are, at bottom, arrangements for getting energy out of food and oxygen. The reasons we breathe are to take in the oxygen we need for this slow combustion of our food, and to get rid of some of the waste

products which are made as a result of the slow combustion.

A great deal of the energy which is produced in this way is needed for our movements. We studied how muscles move food and blood about inside our bodies, and move us from place to place with the aid of the levers provided by our skeleton. Then we studied the nerves and the sense-organs and the brain, and found out how the muscles only moved when they got messages from motor nerves and how motor nerves only made muscles move when they received messages from the sense-organs or from the brain.

Thus your breathing and your eating provide you with energy, your muscles use some of that energy to produce movements, your sense-organs provide you with information about the outside world, and your brain and the rest of your nervous system arranges that your movements are controlled in relation to this information.

In the same way, in a motor-car you need fuel and air, you need the engine to make the car move, and you must have someone to steer the car and control its movements.

Not all the energy set free in our bodies goes to produce movement. Some of it produces heat; and in the next chapters we shall talk about what happens to this.

CHAPTER IV

HEAT AND TEMPERATURE

Temperature and Heat—Measuring Temperature—How Heat Travels—Some Results of the Rules of Heat—Heat is Needed for Melting and Boiling—Melting-Points and Boiling-Points

WHEN you are ill, the doctor takes your temperature with his clinical thermometer. Usually your temperature is 98·4 degrees on the Fahrenheit scale, written 98·4° F. for short.[1] This is called your normal temperature. A few people have their normal temperature a little higher or a little lower, but this is the average. If you are feverish, your temperature may go up to over 104° F.; and sometimes, for instance, often after you have just got rid of a fever, it goes down below normal. But most people go through life without their temperatures varying more than 8 or 10 degrees Fahrenheit altogether.

We are so accustomed to keeping always at nearly the same temperature that we usually do not give it a thought. But really it is a very wonderful thing. Practically no animals except birds and mammals can do this: the temperature of most animals and all plants goes up and down with the temperature of the air or water round them, just as happens to a stone or a piece of wood. And as their temperature goes up or down, so their activity goes up or down. You do not see any insects out of doors in the middle of winter, because they are so cold that their

[1] We shall explain about temperature scales later in this chapter.

body machinery cannot work. Either they die, or else they *hibernate*, which means passing the cold time of year in an inactive condition as if they were asleep.

Animals like this are usually called cold-blooded, but they really are animals with changing temperature; and "warm-blooded" animals like birds or horses should really be called animals with steady temperature.

This effect of cold in slowing down activity and of heat in speeding it up can easily be measured in some variable-temperature animals. For instance, Professor Shapley, in America, found that the pace at which ants walked along the paths near their nest increased very regularly as the temperature of the air went up—so regularly, in fact, that he could use the ants as a thermometer, and tell the temperature to within a degree or so by measuring the rate at which they were walking.

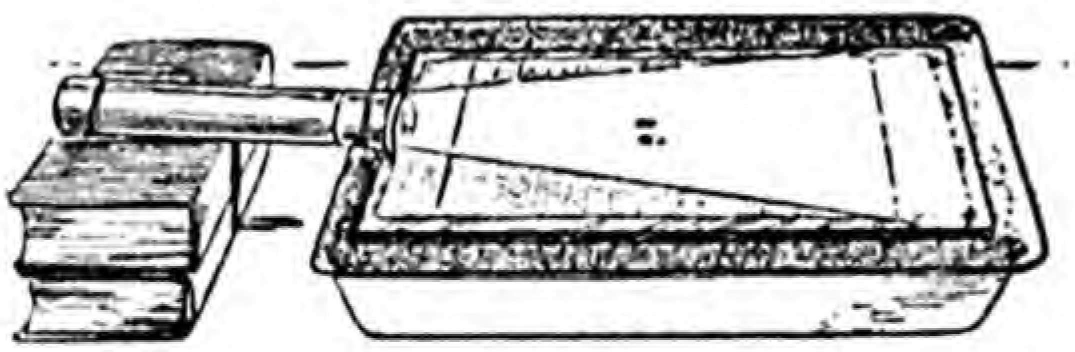


FIG. 59.—*Blowfly maggots crawl away from light. When they are warm, crawling on a warm surface, as here on paper over a glass plate placed on hot sand, they go faster than when they are cold, on a cold surface.*

To show this, an experiment can be arranged with blowfly maggots, or gentles as they are often called (see Book I, Fig. 13). These can be got by leaving a piece of meat to decay in hot weather; blowflies lay eggs in the meat, and in about a week these grow into maggots: or they can be procured from shops which sell them to anglers for bait. Blowfly maggots always move straight away from light. If one of them is put near one end of a piece of paper with two lines across it, say six inches apart, and a flashlight is then shone on it, it will begin to crawl away, and you can measure the time it takes to crawl the six inches between

the marks. Try this first with the paper on the table. Then put the paper on a sheet of glass, and put glass and paper on finely-crushed ice in a dish, and, after giving the glass time to cool down, try again. Finally, try once

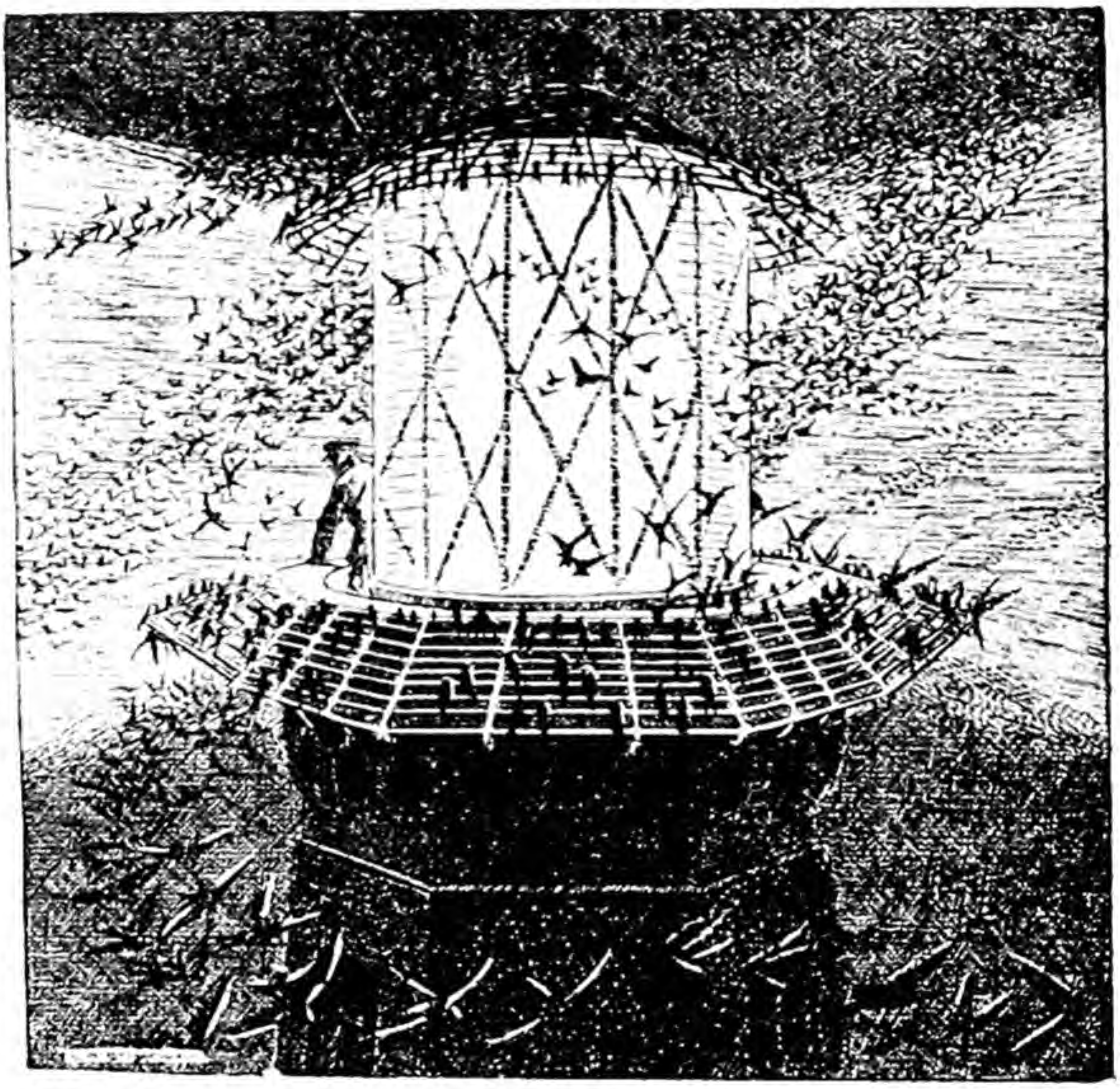


FIG. 60.—*Migrating birds. At night, migrating birds are attracted by the strong light of lighthouses. To prevent them killing themselves, perches have been put up round some lighthouses. This perch was put up by the Royal Society for the Protection of Birds on the St. Catherine's Light, Isle of Wight.*

more with the plate resting on warm sand—say at about blood-heat. Before starting, warm or cool the maggots too by putting the tube in which you keep them on the sand or the ice. In each case take the temperature, letting the thermometer bulb rest on the glass. You will find

that the same maggots will go very slowly on the cold ice, very quickly on the hot sand. They go about twice as fast for each 15° F. that their temperature rises.

So in cold weather an animal with a steady temperature can still be just as active as in hot weather, while an animal with a changeable temperature gets sluggish. That is why insects and frogs and snakes and snails and spiders are not generally seen in winter in countries like England. It is a good exercise to make a rough list of the number of different kinds of animals to be seen out of doors in the neighbourhood of the school during the three summer months and the three winter months. There are many birds which breed in England but migrate southwards for the winter. This is not because they could not keep warm, but because they live on insects, and there is nothing for them to eat in the winter-time.

For the same reason, animals with changeable temperatures get scarcer and scarcer the further you go towards the Poles. In the tropics, insects are the most abundant of all creatures, and there are about as many kinds of reptiles as of mammals: tropical reptiles include many kinds of snakes, lizards, crocodiles, tortoises, and turtles. But in the Arctic there are no reptiles at all, and very few kinds of insects, because animals like these, with a variable temperature, are at such a great disadvantage in a cold climate. They would have to hibernate for over six months in each year, and even during the rest of the time could not be nearly so active as a bird or a mammal.

Temperature and Heat

Birds and mammals, as we have seen, keep their temperature steady, or constant, as it is usually called, and this is an obvious advantage to them. The next step is to try to understand how they keep their temperature constant. But, before we can do this, we must learn something more about heat and temperature in general.

Heat, as we found in Book I, is a form of energy. We know that we can use heat to drive engines as well as to warm ourselves or to dry things; and we learnt that we can get heat from burning and other chemical changes, from rubbing and friction, from an electric current passing along a thin wire, and in other ways. But what about temperature? We know that we feel unpleasantly hot when we are ill and "have a temperature." But we can feel terribly hot, on a hot day, without our temperature changing at all.

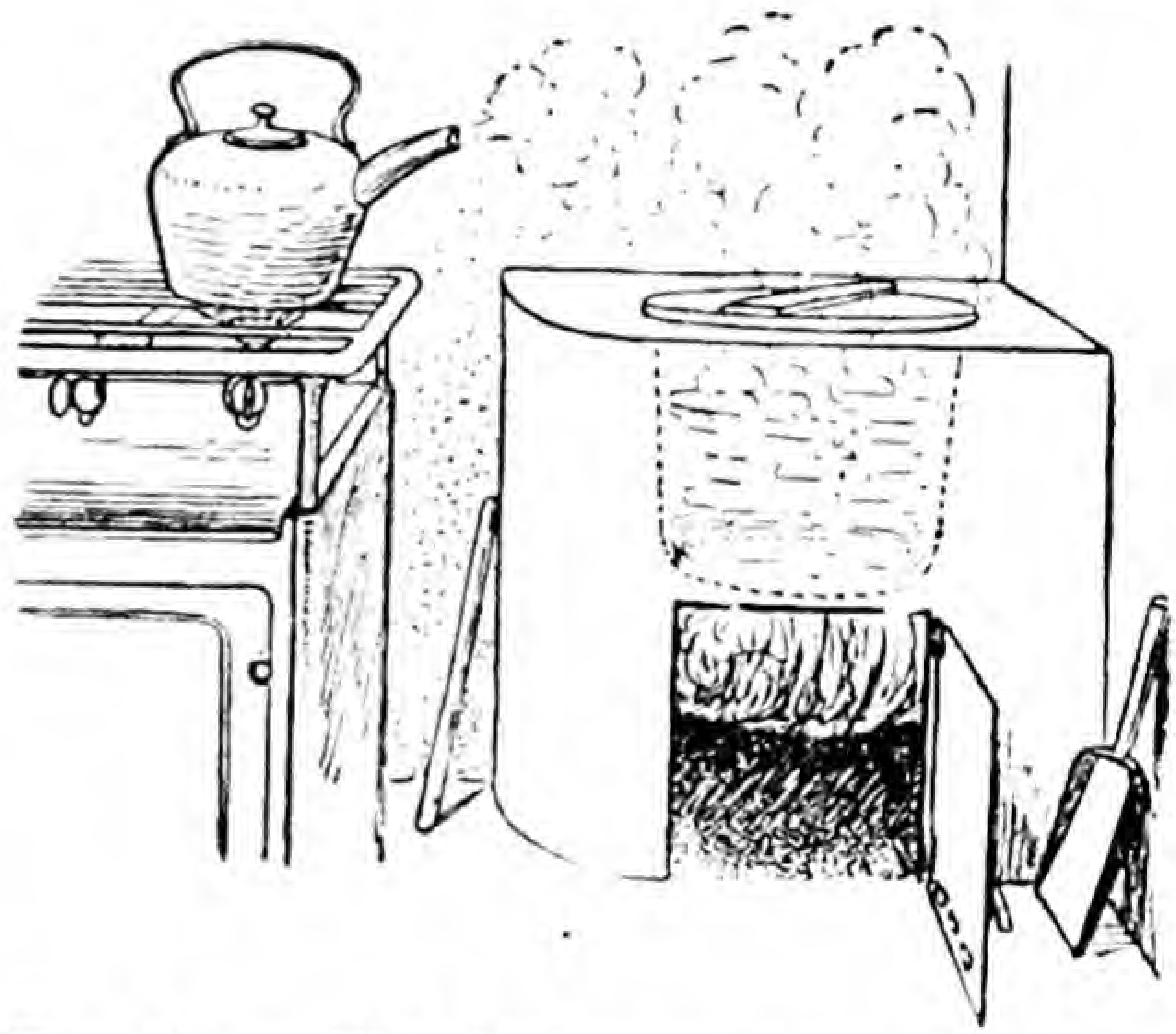


Fig. 61.—*The boiling water in the kettle is at the same temperature as that in the copper: but it takes much more heat to bring the copper to the boil.*

It is very important to understand clearly the difference between heat and temperature. Suppose that we think of two furnaces, both full of glowing coal, but one a very small furnace, say in a small locomotive, and the other a very large furnace, on an Atlantic liner. You would say that they are both equally hot; in science we

say that the temperature of both is the same. But the big furnace will contain much more heat; for the energy which it supplies will drive a much bigger engine than that of the small furnace. Again, imagine a small kettle full of boiling water and a copper full of boiling water. The temperature of the two is the same, but the gas-ring which will bring the kettle to the boil in a few minutes may take an hour to bring the copperful of water to the boil. We have therefore to put much more heat into the copperful than into the kettleful. The amount of heat in boiling water depends upon the quantity of water. There is twice as much heat in two pounds of boiling water as there is in one pound, but all boiling water is at the same temperature.

Two things which touch one another very closely soon come to the same temperature at the point where they touch, but they may have quite different amounts of heat in them. Suppose, for instance, that we put a lump of lead weighing a pound in a saucepan of water, and boil the water. The lead and the water will both become equally hot: they will both be at the temperature of boiling water. Meanwhile, let us have ready two large glass beakers each containing a pound of water from the same tap, and so at the same temperature. We quickly pull the lead out of the boiling water, and put it into one beaker, while into the other we pour a pound of the boiling water, which we can easily do by marking on the beaker beforehand the level at which two pounds of water stand, and pouring in boiling water till this level is reached. You will find that the water in the second beaker will be too hot to put your hand in: while the water to which the pound of lead was added is scarcely lukewarm. Clearly, then, a pound of water at the temperature of boiling

water contains much more heat than a pound of lead at the same temperature.

Finally, let us take two beakers, each containing about the same quantity of boiling water, and let us pour one into a pail full of cold water, the other into a beaker containing a small quantity of cold water. Of course, the pailful will scarcely be any warmer after the boiling water has been added, or, in scientific language, the temperature will have risen very little, while the temperature of the beakerful of water will have risen a great deal. We have, however, added the same quantity of heat to each. From this and the other experiments just described, we learn that the temperature to which a body rises when we add a certain fixed quantity of heat depends upon the kind of stuff of which the body is made, and upon how much there is of it.

Temperature, then, is a condition or state of a body, which we can alter by adding or taking away heat. Heat is a form of energy, which we can have in either large or small quantities: it is not a mere condition. If there is a difference of temperature between two bodies, and they touch one another, heat will pass from the body at high temperature—the hot one—to the body at lower temperature—the cold one—no matter what the weights or sizes or shapes of the bodies are, or what they are made of. When we put the hot lead into the cold water heat passes from the lead into the water, so that the lead gets colder and the water hotter, until they are at the same temperature. If there is very little water the final temperature is higher than if there is a lot of water, but whether there is much or little, heat will pass from the lead to the water until they are equally hot. If cold lead is put into hot water, heat passes from the

water to the lead. Temperature, then, is the condition that fixes whether heat shall flow, and if so, from which body to which.

We have somewhat the same kind of thing when we consider the flow of water. Suppose that we have two vessels containing water, joined by a pipe which is closed by a tap. If we open the tap, the water will flow from the vessel in which the level is higher to the vessel in which it is lower until the surface of the water stands at the same level in both. It does not matter which vessel is the bigger: one may hold fifty times as much water as the other, but the level is the only thing that fixes the direction in which the water shall flow. Temperature is something like the height of the surface of the water above the ground-level, heat something like the water itself, so that we may call temperature a "heat-level." If we put water into a vessel we raise the level: if we put heat into a body we raise the temperature. How much water is required to raise the level an inch will depend upon the size and shape of the vessel: how much heat is required to raise the temperature a degree will depend upon the weight and substance of the body.

There is, however, a very real difference between what happens with heat and what happens with water. Water is a thing, heat is not; water is a substance, heat is a form of energy. When you connect two vessels in which water is standing at different levels, a certain amount of weighable matter passes from one to the other as the height of water settles down to the same level. But when you put the hot lead in the cold water and they both settle down to the same moderate temperature, no substance passes from one to the other: the water becomes warmer, the lead colder, but they both weigh just the

same as they did before. The only way in which you can tell what has happened is by feeling how hot they are with your fingers, or, if you want to be accurate, by taking their temperature with a thermometer.

In science we do not consider heat and cold as two different things: a cold body is one that is at a low temperature, and a hot one is at a high temperature, but there is no particular temperature at which a body ceases to be cold and becomes hot. Hot and cold are just words to express our feelings. Even things that we call cold, like ice, have some heat in them, but a warm thing has more. We talk of rich men and poor men; but even a poor man has a little money, though a rich man has more. In science we should talk of *degrees of property*, and say that the poor man had a very small degree of property, a rich man a large degree of property. There is not, then, a science of heat and a science of cold, but one science of heat, in which we consider hot and cold things together.

Measuring Temperature

Temperature, as we have seen, is a word for heat-level. It is often of great practical importance to be able to measure temperature accurately. For instance, it is important for a doctor to know the exact temperature of his patients; and in making things in factories, it is often necessary for a particular chemical process to go on at a definite temperature if it is to have good results. In engineering, the exact temperature of the boiler and other parts of the engine must be known and taken into consideration by the man who designs the engines. The proper heating of buildings, the design of cold-storage rooms, the tempering of metals, the manufacture of electric lamps and the sterilizing of surgical instruments.

are a few of the things where a careful measurement of temperature is of the greatest importance.

Before the seventeenth century, no instruments had been invented for measuring temperature, and men had to rely on the feel of things. This, however, is not at all satisfactory. For one thing, our feelings do not give any accurate measure of temperature; we can only say that a thing feels very cold, cold, cool, warm, hot, or very hot. For another, our sense of heat and cold is not really suited to give an accurate answer about the temperature of things. On a cold day, for instance, if you touch an iron railing and a wooden railing, the iron will feel much colder than the wood, although both are actually at the temperature of the air around them, and so at the same temperature.

The reason for this is that different bodies allow heat to travel along them with different degrees of ease. Metals, especially copper and silver, lead away, or "conduct," as it is called, the heat very readily: wood conducts heat not nearly so well, and wool conducts worse still. When, therefore, we touch a piece of cold iron we warm it up a little just under our finger, but the heat so put into it travels away quickly along the iron, and then fresh heat passes in from our finger to the part just underneath, and again travels away. Heat is therefore all the time passing from our finger, and the surface of it, where the sense-organs are, gets very cold. When we touch a piece of cold woollen cloth, however, a little heat from our finger soon warms up the cloth just under our finger, and that heat stays there, since heat can hardly travel at all along wool. In this case, then, after the first little passage of heat from our finger, things are steady, and we do not have the heat draining away from us all the time. In the same way, if you leave a wooden or horn spoon and a metal spoon in

very hot water, you can pick out the wooden or the horn spoon without burning your fingers, but the metal spoon will feel unpleasantly hot. In this case it is a question of heat passing to your fingers. Think for yourself exactly why the wooden and the horn spoon do not burn you, although they are as hot as the metal spoon.

Finally, there is another reason why our sense-organs are no good for measuring temperature accurately. Our temperature sense is concerned more with telling us about *changes* in temperature than with giving information as to the precise level of temperature. You can do a very simple experiment to show this. Take three bowls of water, one very cold, one nearly as hot as you can bear, and one tepid. Put one hand into the cold water, the other into the hot water, and keep them there for about a minute. Then put both hands in the lukewarm water. You will find that it feels cold to the hand that has been in the hot water, but hot to the other hand, which has been in the cold water; and yet of course it is all at the same temperature. This means that how hot or how cold things feel to us will depend partly on how cold or how hot we have been just beforehand.

FIG. 62.—*Put one hand in hot water and the other in cold, and then both in tepid water. The tepid water will feel cold to the hot hand and hot to the cold hand.*

It was therefore a great step forward when instruments were invented for the proper measurement of temperature. An instrument of this sort is called a *thermometer*. Ordinary thermometers depend for their working on the fact which

we learnt in Book I, that most things, whether solids, liquids, or gases, expand steadily as they are heated.[1] The rails of a railway give us an example of the expansion of solids. If you look, you will see that the separate strips of each rail are laid so that their ends do not quite touch, which gives the tiny jarring, too faint to be called bumping, which you feel each time the wheel of your carriage goes over a gap between two lengths of rail. This is to allow for very hot weather, which makes the rails expand. Steel expands by about six parts in a million for every degree Fahrenheit it is warmed, so that a strip of rail 60 feet long at twenty degrees below freezing will be half an inch longer at a temperature of 100° F., which it might easily reach in the sun on a hot summer's day. So if there were no gaps at ordinary temperatures, the expansion in hot weather would force the rails out of line.

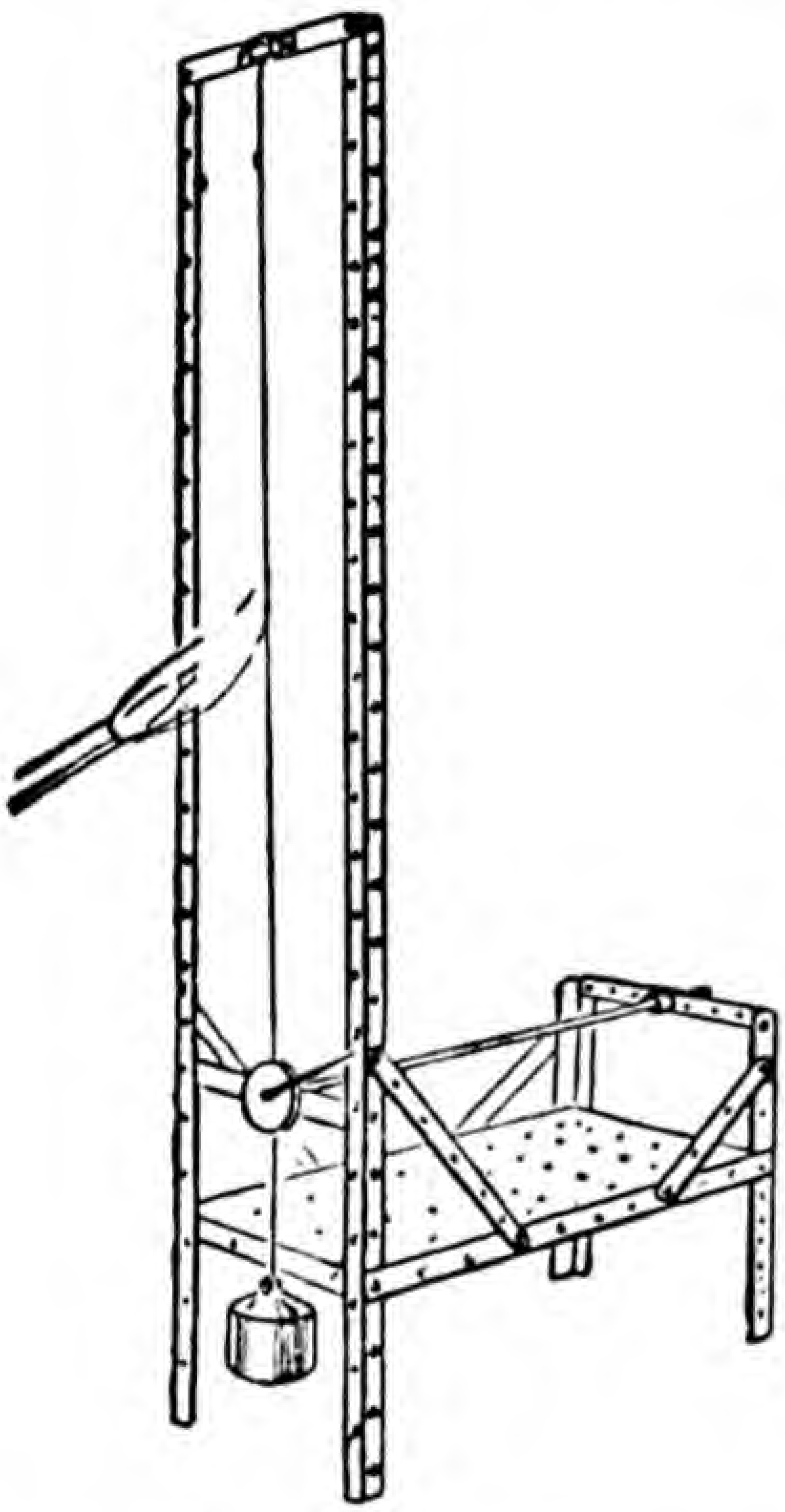


FIG 63.—*An apparatus made of Meccano parts, to show that copper wire expands when heated.*

Telephone and telegraph wires are another good example. In summer these sag between the poles more than they do in winter, because the wire has expanded and each stretch of it is longer. So when men are putting up a line of wire and the weather is warm, they must be careful not

[1] Water is one of the few exceptions: when heated from 0° C., it first contracts, and only begins to expand with heat at temperatures above 39° F.

to stretch it tight between poles, or otherwise when the winter comes the cold will make the wire shrink so much that it breaks.

You can do a simple experiment to show the expansion of metals. Fix a copper wire to the end of a projecting piece of metal, wind it once round a metal pulley, and hang a weight on to its free end. Fix a wooden pointer on to the outside of the pulley with sealing-wax, and arrange a scale opposite its free end. The picture shows the set-up: you can use Meccano for some of the parts. Then heat the wire above the pulley with a bunsen burner. The wire will expand: as a result the weight will drop a little, and the pulley will roll round as it drops; and the movement is magnified by the free end of the pointer (Fig. 63).

The ordinary thermometer is a glass bulb with a long thin stem: it contains some mercury, which at low temperatures fills the bulb and a small part of the stem. When the mercury is heated, it expands a little, and the purpose of the stem is to make the expansion easily seen, because a very little mercury occupies a long length of a fine tube. You can easily see that an increase of size of the mercury which would mean only a very small rise in level in a wide tube like that of which the bulb is made, will mean a large rise in level in a very fine tube like that of which the stem is made. The finer the stem is made, the bigger the rise of the mercury thread which we get for one degree increase in temperature, supposing that the bulb is the same size in both cases.

Nearly all solids and liquids expand when they are heated. The glass of which the thermometer is made itself expands, but the mercury expands more, so that as a net result we have the mercury rising in the glass which contains it. If you dip a thermometer into hot water, and

watch very carefully, you will see the mercury drop quickly for an instant before it begins its upward movement. This is because when the thermometer is first put into the hot water, the glass gets hot before the heat passes to the mercury, so that for a moment we have the glass bulb bigger, and the mercury still cold, and so still the same size. As soon as the heat has passed to the mercury, it too begins to expand, and then starts shooting up the tube.

Mercury is particularly suitable for use as the liquid in thermometers because it does not wet the glass, as water and other liquids do; it takes little heat to raise its temperature; it conducts heat very well; it does not boil until it reaches a very much higher temperature than the boiling-point of water; and it does not freeze until it is at a much lower temperature than the freezing-point of water. Other liquids are, however, sometimes used, such as alcohol, coloured red to make it more easily seen. Alcohol freezes at a temperature even lower than the freezing-point of mercury, so that such thermometers are often used in the polar regions, where it is sometimes so cold that the mercury in the ordinary thermometers freezes.

The liquid rising or falling in the tube tells you that the temperature of the bulb is higher or lower than it was: but it does not tell you just how much higher or how much lower. For this, you must have a tube of exactly the same width all the way up; then the distance which the liquid moves in the tube will be an accurate measure of the change of temperature.

Further, if you are to know exactly what the temperature of the bulb is when the liquid in the tube stands at a particular level, you must have a fixed scale of temperature marked on the tube. To do this, the makers of thermometers take advantage of two facts which we shall talk

of later, namely that in ordinary conditions water always boils at exactly the same temperature, and ice always melts at exactly the same temperature. So if you put the bulb of your thermometer in melting ice and mark where the liquid stands in the tube, and then do the same when you put the bulb in the steam from boiling water, you have two fixed points for your temperature scale. If the bore of your tube is the same thickness throughout its length, you can be certain that for each equal rise in the temperature of the liquid, it will move an equal distance up the tube—in other words, the distance the liquid moves up or down the tube will be proportional to the going-up or going-down of its temperature—and so you can divide up the space between your two fixed points into small equal divisions, to mark "degrees of temperature."

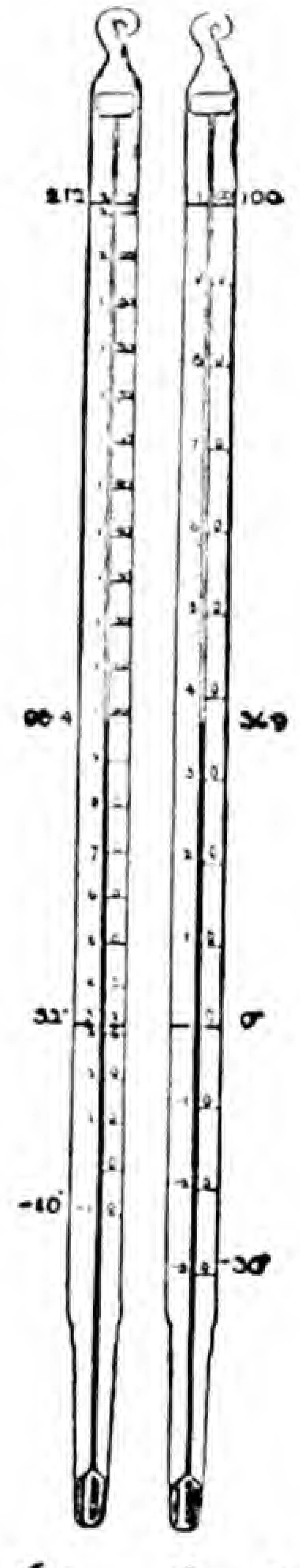


FIG. 64.—*Scales of temperature. Two thermometers, the one on the left with a Fahrenheit scale, the one on the right with a Centigrade scale.*

The most convenient way of dividing up the scale is to call the melting-point of ice nought degrees (written 0°, the little circle meaning degrees) and the boiling-point of water 100°—a hundred degrees. A thermometer divided like this is called a Centigrade (which means "hundred-degree") thermometer. Unfortunately in this country and in the United States most people go on using a more complicated scale, where the melting-point of ice is called 32 degrees, and the boiling-point of water 212 degrees.

This arrangement is called the Fahrenheit scale, after the distinguished man of science who introduced it; we need not go into his reasons for adopting this scale, though they seemed good at the time. The Centigrade scale is always used in science. To distinguish degrees on the two scales we write C. or F. after them. So the melting-point of ice$=0°$ C.$=32°$ F., and the boiling-point of water$=100°$ C.$=212°$ F.[1]

Temperatures below nought will be called minus so many degrees. For instance, if you add salt to water to make brine, the brine will not freeze until its temperature is well below the freezing-point of water. The freezing-point of saturated brine—that is, water with as much salt dissolved in it as it can hold—is minus 22 degrees Centigrade, or, as it is generally written, $-22°$ C. This fact about brine, by the way, explains why salt is sometimes put on the snow to clear the streets after a snowfall; the mixture of salt and snow becomes liquid and will drain away. However, this is not very healthy, as the salt slush is much colder than slush from melting snow, and people's feet get badly chilled.

It is a simple exercise in arithmetic to express Fahrenheit temperatures in Centigrade degrees. To do this, subtract 32 from the number of degrees Fahrenheit, and then multiply by $\frac{5}{9}$, since 180° F. equals 100° C. To do things the other way round and turn Centigrade into Fahrenheit, you must multiply by $\frac{9}{5}$ and then add 32. For instance, the normal temperature of your body is 98·4° F. On the Centigrade scale this is $\frac{5}{9}(98{\cdot}4-32)=\frac{5}{9}\times 66{\cdot}4=36{\cdot}9°$ C. There is one temperature at which both Fahrenheit and Centigrade thermometers will show the

[1] This is at ordinary pressure. The boiling-point of water changes with the pressure of the air, as we shall see later in this chapter.

same number of degrees. Try and work out what this temperature is. Clearly it will be below freezing-point.

How Heat Travels

Our own temperature stays steady at a little more than a third of the way up between freezing and boiling. But we still have some more things to learn about heat in general before we can understand how our bodies manage to keep their temperature constant.

We have already said that when two things at different temperatures touch one another closely, heat will travel from one to the other, and have also spoken of the way in which heat travels, or is conducted, along pieces of metal or wood. Let us consider this *conduction* of heat a little more closely. If one end of a poker is in the fire, the other end, the handle, gets hot, heat being conducted up the poker. As the poker is solid, it is impossible for bits of it to move from the end in the fire to the end in the air, as could happen to water inside a metal tube. What happens is that the bits of the poker that are in the fire pass on some of their heat to their neighbours, and so on, all the way along to the handle. The rest of the heat escapes to the surroundings from the sides of the poker, or the handle would get as hot as the end in the fire. As we have seen, wood and wool conduct heat much worse than metals. Glass, too, is a very bad conductor. If you take a bit of glass rod and a bit of copper or iron rod of the same size and shape, and put their ends in a flame, you will be able to hold the glass rod comfortably much nearer to the flame than you can hold the metal rod. You can even melt the tip of a glass rod which you are holding. This would be quite impossible with a copper rod, for

your hand would be badly burnt long before the part in the flame was hot enough to melt.

As we have seen, metals conduct heat. All metals are good heat-conductors. Polar explorers never touch metal things with their bare hands in really cold weather, because the metal conducts heat away from their fingers so quickly that the living substance freezes and the man gets frost-bite. It would not hurt to pick up a very small piece of very cold metal, like a pin, because quite a small amount of heat would bring it to the same temperature as the man's body, and then his fingers could lose no more heat to the pin. But a gun-barrel or even a knife-blade would be dangerous to touch.

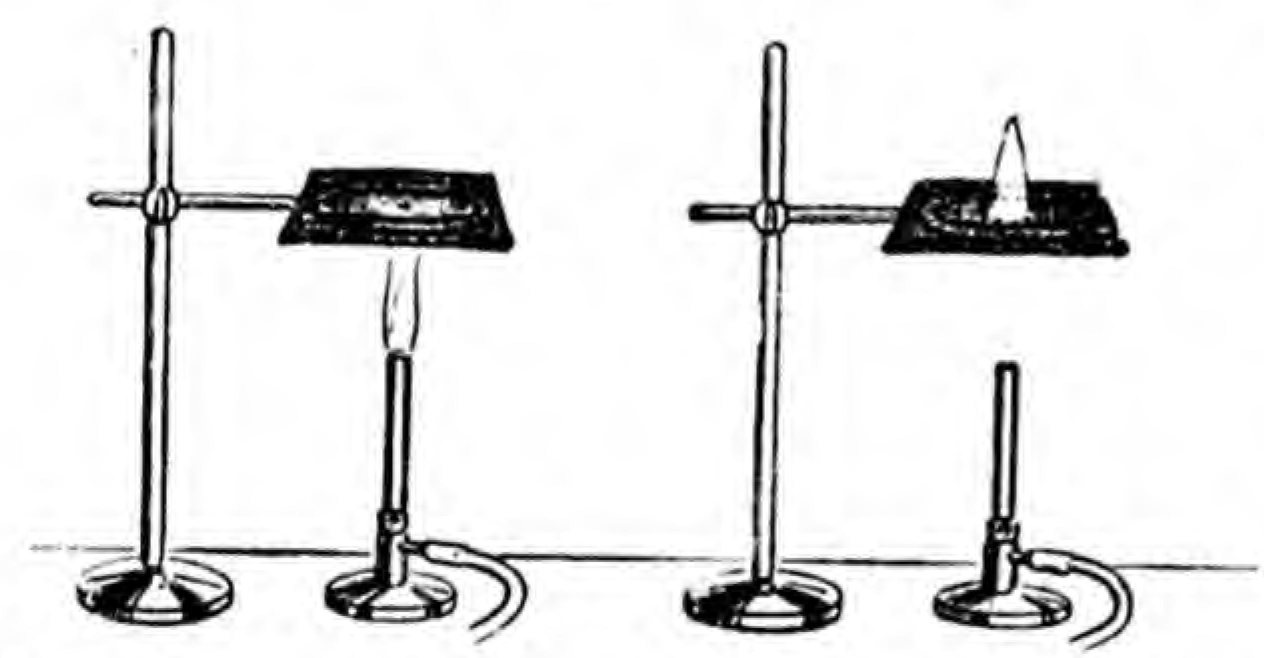


FIG. 65.—*The flame of a bunsen burner will not spread through wire gauze.*

If you put a bunsen burner so that its top is an inch or so below a piece of wire gauze, turn on the gas, and then put a lighted match above the gauze, the gas will light above the gauze, but not below. The reason for this is that the metal of which the wire gauze is made conducts the heat of the flame away so fast to the sides that the temperature under the gauze is not high enough to set the gas alight. In the same way, if you put your lighted match in the gas, just where it comes out of the burner, you will get no flame above the gauze, only below it, as shown in the picture.

This property of metal gauze is used in mines to prevent explosions. In mines, gases are sometimes given off by the coal which mix with the air and produce terrible explosions if they are lit. To prevent the lamps which the

miners carry from exploding these gases, they are made with fine-meshed wire gauze surrounding the flame. Even if the explosive gas is all around, only the small amount of it which gets inside the gauze is set alight; the flame will not spread through and explode all the gas outside. These lamps are called Davy Lamps, after the great scientist Sir Humphry Davy, who, by inventing them, saved thousands of lives.

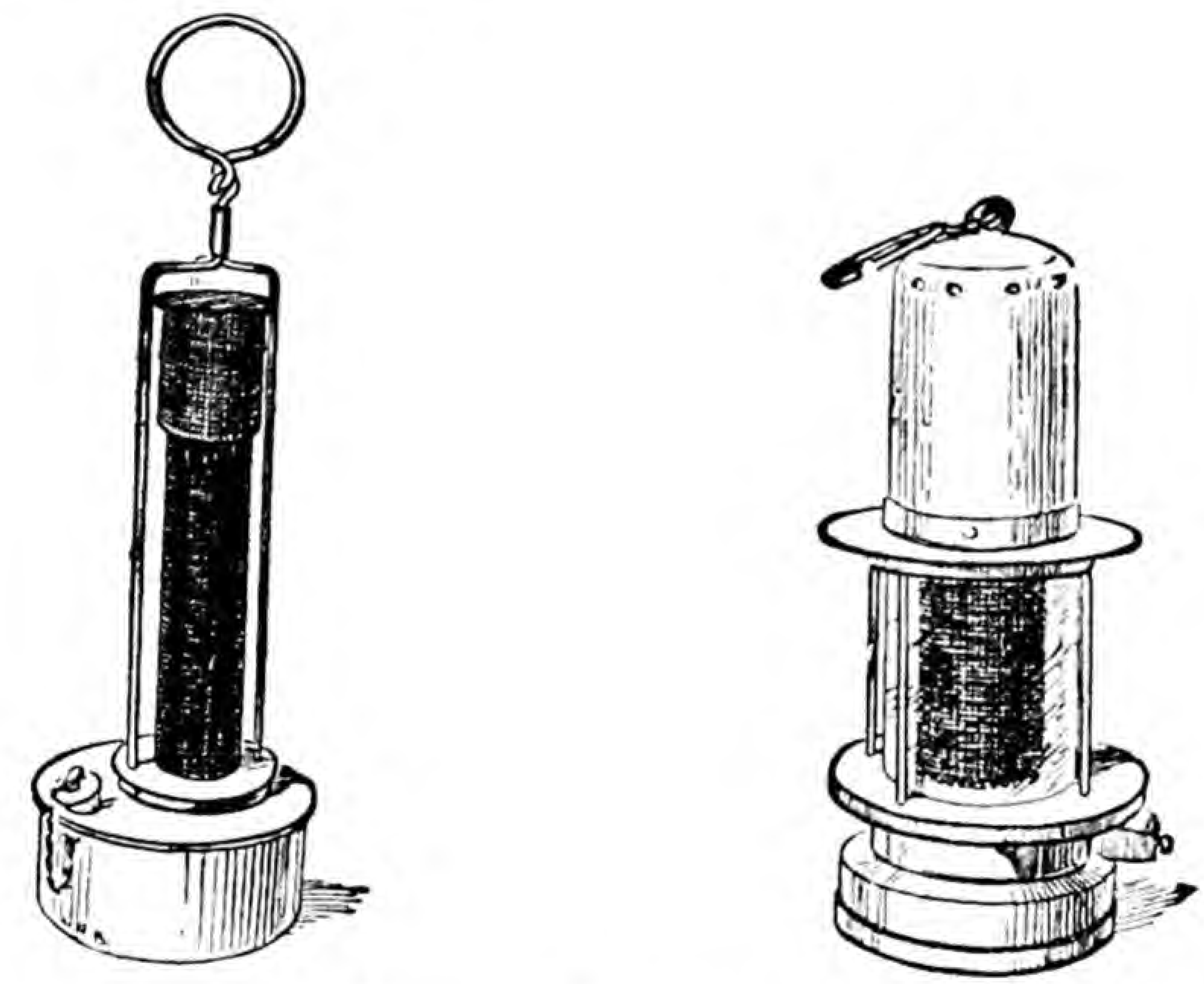


FIG. 66.—*Davy lamps. Left, an early type* (1817)*; right, a modern pattern, with glass screening the wire gauze.*

However, not all metals conduct heat equally well. If you have a metal vessel, like that shown in the picture, with holes in the bottom, you can stick rods of different metals through corks in the holes. Suppose you take three rods about 18 inches long, one of iron, one of brass, and one of copper, and fix them with their ends sticking up about 2 inches into the vessel, and then fill the vessel with boiling water. If you touch the outer ends of the

rods, you will find that the copper one feels hottest, the iron one the least hot, though of course the ends in the water are all at the same temperature. This is because copper conducts heat better than brass, and brass better than iron. You can show this still better by having light metal rings made so that they will just slip along the rods; before pouring in the boiling water, you stick these rings to the rods just outside the vessel with a little paraffin wax. When you put the boiling water in, the metal of the rods near the vessel soon gets hot enough to melt the wax, and the rings start slipping down. They go on slipping until they reach a point where the temperature of the rod is just low enough for the wax to go solid. You will find that the ring on the copper rod goes a long way down before sticking, while that on the iron rod stops only a few inches from the hot water. Paper arrows can be stuck on the rings, as in the picture, so that their positions can be seen more easily.

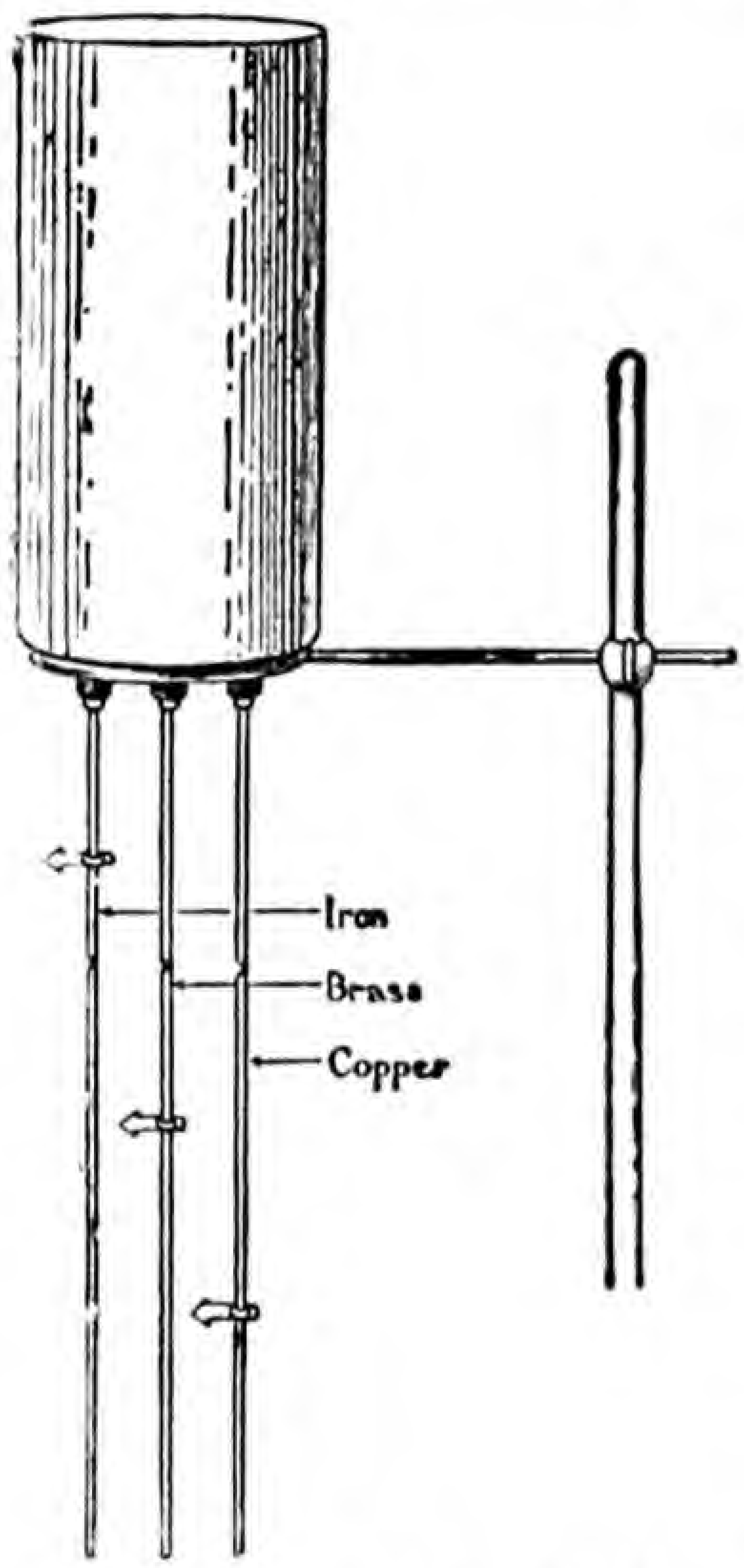


FIG. 67.—*An experiment to show that some metals conduct heat better than others.*

There are, however, other ways in which heat can travel. Suppose we hang up a hot ball of iron by a fine wire: it soon gets cold, although the wire is so narrow that very little heat can travel along it. Or suppose we put a hot teapot on a tile or glass plate, which conducts heat very badly: it, too, soon gets cold. The heat must be escaping in some other way than by conduction. If we put a

tea-cosy over the teapot, it stays hot much longer. In the unprotected pot, therefore, heat must be escaping from the surface. How?

There are two ways. In the first place, the air touching the pot becomes hot and rises. New air comes in to fill its place, takes some more heat from the teapot, and rises in its turn. When heat travels in this way we call it *convection*, which means being carried about. When there is convection of heat, hot bits of matter carry the heat from place to place; when there is conduction, the bits of matter do not move, but one bit hands on heat to its neighbours. Because of this, you cannot get convection in solid things, but only in liquids or gases whose parts can move about freely. Convection is a common way for heat to travel. A hot wind consists of warm air that is moving from one place to another. As we saw in Book I, if you heat water in a test-tube or a flask by putting a flame underneath it, the water close to the flame is heated, and then, since hot water is lighter than cold, it moves up, and cold water takes its place until all the water is heated. Ocean currents can carry heat for thousands of miles in the sea. The Gulf Stream is a current which flows from hot tropical seas to the north-west coasts of Europe. The heat which is carried in this current is very important to us: it is enough to make the climate of Great Britain and Scandinavia much milder than it otherwise would be.

In gases and in liquids much more heat is usually conveyed by convection than by conduction: in fact, both liquids and gases conduct heat very badly. We had an example of this in Chapter I of Book I when we made the experiment of heating the top part of a test-tube full of water. If you do this, you can get the top layer boiling

merrily, while the bottom layer stays almost as cold as before.

You can do a very simple experiment to show the convection of heat in water. Get a piece of glass tubing bent into the shape shown in the picture, fill it with water, and drop a crystal of permanganate of potash into it. Then heat one side of the tube with a bunsen burner. The heated water rises, cold water is drawn in to take its place, and so the water in the tube starts to circulate round and round. As the permanganate dissolves it colours the water, and you can actually see the coloured water circulating.

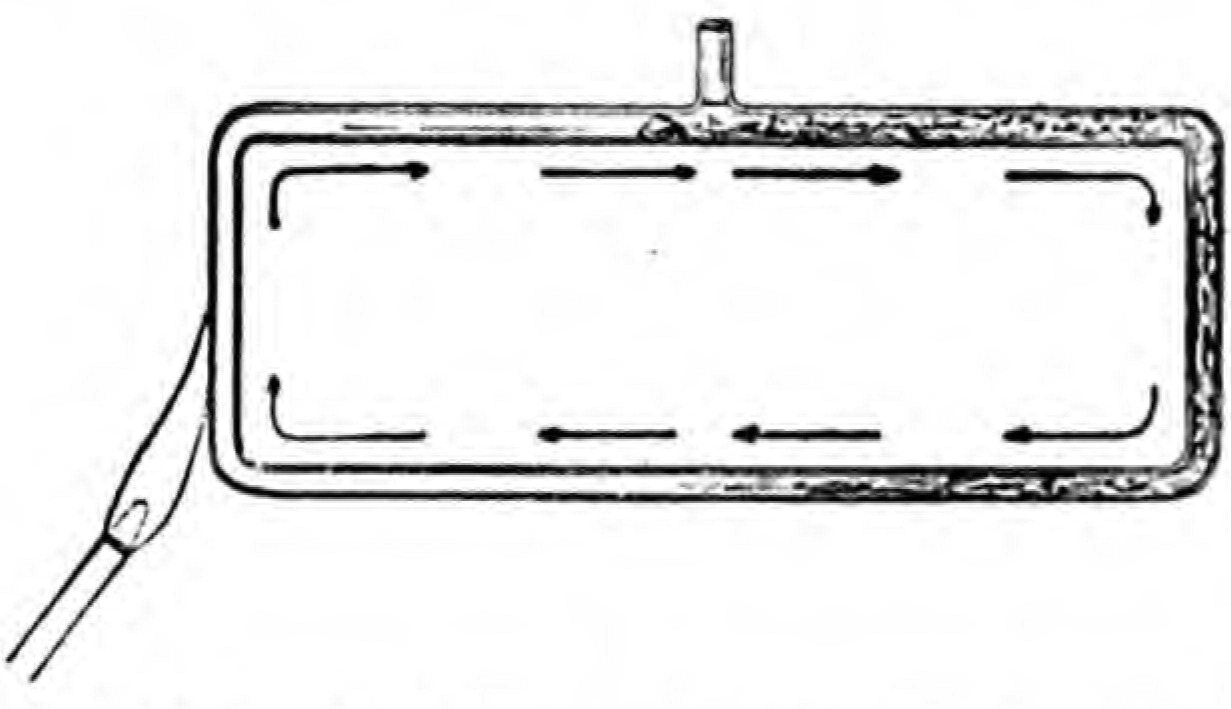


Fig. 68.—*Making water circulate by heat. The crystal as it dissolves colours the water, so that the current in the tube can be seen.*

This illustrates the principle used in the ordinary hot-water systems used for heating houses. There is a boiler, which is heated by coal or coke; from the top of this a pipe leads up to the rooms to be heated, and then comes down again to the bottom of the boiler. The heat of the fire makes the water move up out of the top of the boiler, cool water comes in at the bottom to take its place, and so a circulation is set up. In the rooms to be heated, the water is usually led through "radiators." These are simply sections of pipe bent up and down, to provide plenty of surface through which the heat can leak away. They also have taps to regulate the amount of water passing through them.

In the case of the teapot or the hot iron ball, convection is not the only way in which its surface can lose heat. You

may say that the air will conduct some heat away, just as a metal would. Air, however, is a very bad conductor indeed. Some very loosely woven tweeds are very warm. The reason is that there is a lot of air entangled between the threads, which cannot easily move away: it does move, but very slowly, on account of all the fibres in the way. A coat of cloth, therefore, keeps round us a layer of warm air—the coat stops convection in the air. It really clothes us in a sheet of air.

There is a third way in which a body can lose or gain heat, which is called *radiation*. Even if a hot body is put in a vessel and all the air round it is pumped out, it still cools—that is, heat travels out from it. There is hardly any air or gas in ordinary electric light bulbs, so the glowing filament cannot lose heat either by conduction or convection; and yet it makes the glass hot across the empty space.

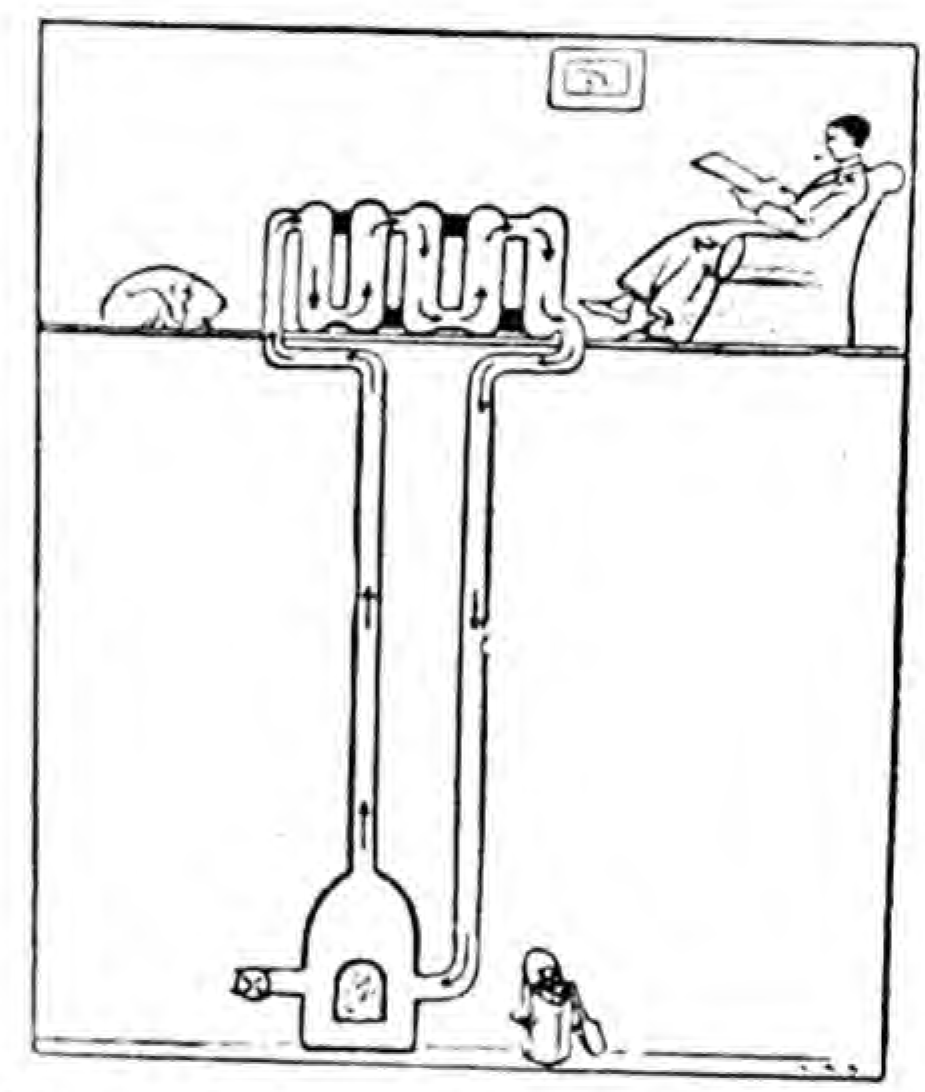


FIG. 69.—*A diagram to show how water circulates in a hot-water heating system. Really there would be many radiators.*

If you hold your hand underneath a hot body, like a metal ball or a hot metal plate, you will feel plenty of heat reaching you from the body. This heat cannot be travelling to you by conduction, as air is such a bad conductor; and it cannot be travelling by convection, as hot air rises. It is travelling by radiation: rays of heat are hitting your hand. If you put your hand the same distance *above* the hot body, it will feel much hotter; this is because heat is now reaching it by convection as well as radiation.

Radiant heat, as we call heat which is being conveyed by radiation, travels in the same way as light does. In fact, light and radiant heat are both very similar forms of the same kind of energy, only our eyes are not made so that they can see radiant heat. We may say that radiant heat is a kind of invisible light: indeed, visible red light carries much heat.

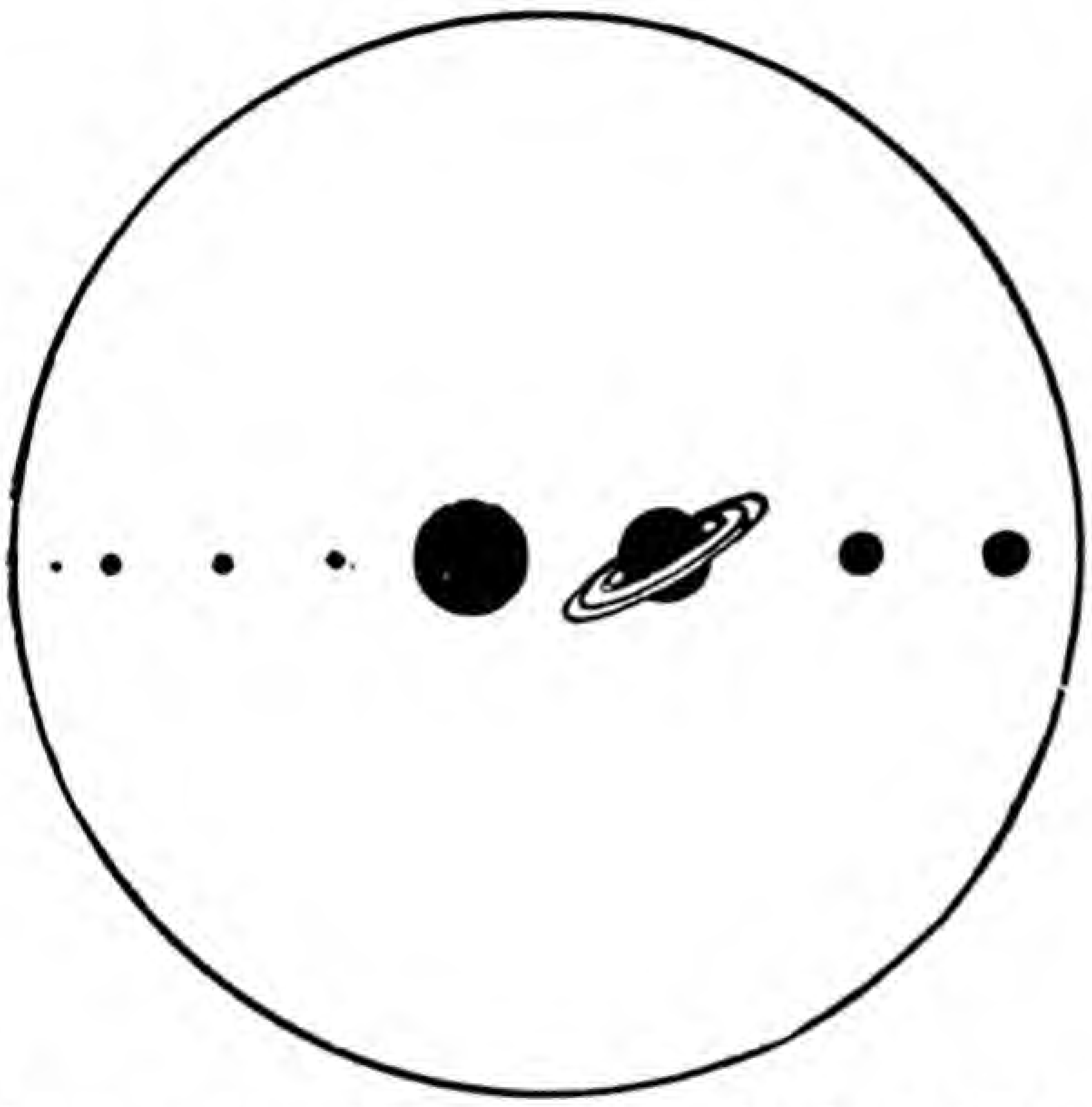


FIG. 70.—*The sun and the planets drawn to the same scale. The planets are arranged according to their distance from the sun: from left to right, Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.*

Heat rays and light rays, as we have said, are very like each other. We call them both *radiation*, and both of them can travel across empty space without there being any matter to serve as a bridge between the two ends of their journey. If this were not so, the sun could not warm us or give us light, for there are over ninety million miles of empty space between the sun and the earth.

It is worth thinking a moment about the sun and the enormous amount of heat it is radiating out of itself. If you took an iron ball about the size of a man's head—say a foot across—to be the sun, then to be in proportion the earth would have to be only the size of a pin's head, one-ninth of an inch across, and would have to be over thirty-five yards away. However hot the iron ball was, only the tiniest fraction of its heat would reach the pin; and yet nothing could live on the earth if it were not for

the correspondingly tiny fraction of the sun's heat which hits us. All the rest, except for equally small amounts that hit the other planets, goes off and gets wasted in empty space. The actual temperature of the sun's surface can be calculated, and is about 6000° C.—a temperature more than twice as high as can be obtained in the hottest furnaces. All the planets together only receive a little more than one-hundred-millionth part of the heat which the sun radiates.

There are these three ways in which heat can travel—by radiation, by convection, and by conduction. Usually the three ways are all at work together. Think of a china teapot full of tea. Inside the pot heat is travelling from the hotter parts of the tea to the colder by convection. The pot is radiating heat out from its surface. Heat is also being conducted from the hot tea to the outer surface of the china. And the pot is also losing heat by convection in the air. Even if there are no currents in the air, the pot makes the air round it lighter by heating it, and the hot air rises and cold air takes its place, so that the teapot is losing heat by warming the air much faster than if there were no convection. In an ordinary central heating system, all three ways are at work too. After the heat is put in by the boiler, it is carried all round the house by the movement of the heated water—convection. Heat is travelling from the inside to the outside of the metal pipes and radiators by conduction. And the radiators heat the rooms, not only by heating the air by convection (and a little by conduction), but by radiating heat out in all directions, so that the heat rays warm the walls and the furniture and everything else which they hit.

Some Results of the Rules of Heat

The facts about the way heat travels have many practical applications, and give rise to some interesting results in nature. We have already mentioned the modern hot-water heating system as one practical application, and ocean currents and winds as important results in nature. Let us look at a few more examples. Radiant heat from a hot body passes freely through empty space, and with little loss through most gases. But it does not pass well through most solid and liquid things, though some of these stop much more radiant heat than others do. Even glass, though it is transparent to light, stops most of the heat: that is why you sometimes see fire-screens made of glass. Of course, the radiating heat-energy from the fire is not lost when it comes to the glass screen. It is stopped from travelling on in the form of heat rays, but the energy stopped warms up the glass itself.

Water, too, stops some radiant heat. That is why powerful magic-lanterns have a little trough filled with water fitted between the light and the lantern slide, to prevent the heat getting to the slides and melting the gelatine film. If the heat is too strong, the water itself will heat up and boil. To prevent this, the troughs used in film projectors have pipes attached, so that a stream of water can be run through them. In this case the unwanted heat is actually carried away by the moving water, not merely stopped by it. If this were not done in cinemas, the film would catch fire from the heat of the arc-light.

When water is in the form of vapour it will stop a good deal of radiant heat; as the air usually contains water vapour, this has important effects on climate. Dry air lets

most of the sun's radiant heat through, but wet air (and still more, of course, clouds, where there are actual water droplets) stops most of it. This makes a great deal of difference to the temperature of the earth's surface. During the day the sun's radiant heat warms up the part of the earth on which it falls: but at night practically no heat falls on the dark part of the earth, and then the warm earth begins to radiate heat away again into space. Clouds and water vapour in the air act as a barrier to this radiating heat, in whichever direction it is going. So where the climate is moist, the ground and the air near it will not get so hot in the daytime, nor so cold in the night-time, as in places with a dry climate.

Deserts are found in very dry parts of the earth where the air has practically no water vapour in it and there are hardly ever any clouds. So deserts are terribly hot in the day, and cool or even really cold at night; there is often as much difference between day and night temperature in a desert like the Sahara as between summer and winter temperature in temperate climates. In a country like England, where there is a good deal of water vapour or cloud in the air, this acts like a blanket and keeps the earth from losing so much of its heat at night (as well as from gaining so much heat during the day).

This will make a difference even from day to day. When there is a little ice on a lake but not enough for skating, skaters hope for a clear, starry night, for that will let much more heat leak away than a cloudy night, and there will be a harder frost. In the same way you are likely to see hoar-frost on the grass after a clear night even in late spring or early autumn, while a cloudy night does not let the temperature of the ground fall below freezing-point.

Even dry air stops some radiant heat. There is no air round the moon, so the surface of the moon is extremely hot when the sun is shining on it, and extremely cold when it is in darkness. In the sun its temperature is probably far above the boiling-point of water; but after it has been a few minutes in the dark the cold is far greater than anything experienced on the earth.

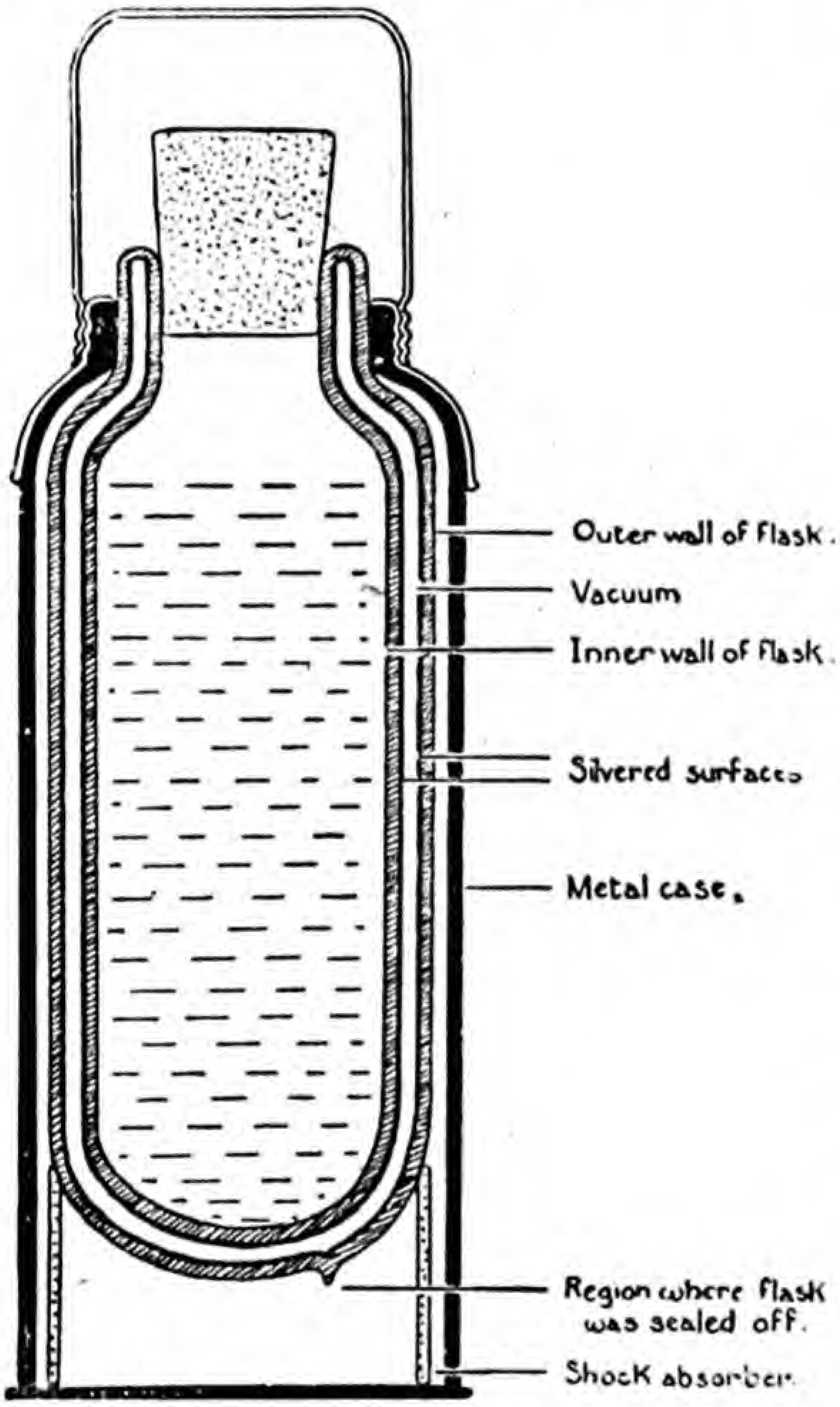


FIG. 71.—*How a vacuum flask ("Thermos bottle") is made.*

The type of flask invented by Sir James Dewar, which is often called a "Thermos" flask, is a quite modern invention in which our knowledge of the rules obeyed by heat is made use of in an interesting way. A "Thermos" flask is an arrangement for keeping hot things hot and cold things cold for a long time. The important part of it is a glass flask with two walls. The space between the two walls is first pumped as free of air as possible, and then the tube through which the air was pumped out is sealed off by melting the glass, which makes the little glass "tail" that is to be seen near the bottom of the flask. Besides this, the inside of the outer wall of the flask is coated with a thin film of silver. The double flask is fitted into a light metal case for

protection, and its neck is corked with an ordinary cork, over which a metal cap is screwed.

Now let us see how the thermos does its work. Let us suppose it is a hot day, and the flask has been filled with iced lemonade. Heat can easily get from the warm air round about to the outside wall of the double-walled flask. But, beyond this, it is hard for it to travel. In the first place, the silver reflects radiant heat just as it does light, and so, of any heat which is reaching the outer wall of the flask by radiation, most is sent back again towards the outside world. But heat also reaches the flask by convection: the warm air touches the glass and heats it up. If there were air between the two glass walls of the flask, it would carry heat by convection from the outer to the inner wall. But there is no air there, since the air was pumped out before the flask was sealed off. So the only heat which can get across is the amount which can radiate across the empty space, and nearly all of this is reflected back at the inner silvered surface, so that very little heat gets to the lemonade inside the flask in this way.

The other way in which the heat can travel is by conduction, from the inner wall of the flask through the rim and down the outer wall; but as glass is a very bad conductor, not much heat can get in by this method.

The only place where there is not a vacuum between the inside and the outside of the flask is in the neck. This is stopped by a cork, and cork too is a very bad conductor of heat. So even here not much heat can pass, although more than over the rest of the flask's surface.

The result is that heat reaches the inner wall of the flask very slowly, and so the iced lemonade stays cold for many hours instead of getting tepid in a few minutes.

The same thing happens, but the other way round, if on a cold day you put boiling tea in the flask. The vacuum and the silvery surface act as barriers in the path of the heat of the tea, which would pass away quickly by convection, conduction and radiation in an ordinary bottle, and so you may still have a hot drink at the end of a long day.

Heat is Needed for Melting and Boiling

Before we go back to our bodies, we have to consider a further point about heat, namely the heat used up in boiling and melting things. If you put two saucepans of hot water on different gas-rings of the stove, and turn the gas on full under one but keep only a very small flame under the other, both will eventually begin to boil. The one with the big flame under it will come to the boil quicker, and will boil away sooner: but it will not get any hotter than the other. Boiling water at ordinary air-pressure is always at the same temperature—100° C. or 212° F.

While the water is boiling away heat is passing into it, and yet its temperature does not go up. Why is this? It is because energy is needed to change water from being a liquid to being the gas which we call steam. If you supply heat to liquid water, you cannot make it hotter than its boiling-point; once it begins to boil, all the new heat you supply goes towards turning more and more of it into steam. (Steam itself, however, after it has left the water, can be led away and still further heated up; it is then called "superheated steam." The steam in some steam-engines is at a temperature of 400° C.) The reverse is true when steam condenses into liquid water: heat is given out in the process. As a matter of fact, the

amount of heat in the two transactions is the same: if a certain quantity of heat is needed to turn a given weight of liquid water into steam, the same quantity of heat will be given out again if the steam condenses.

The amount of heat given out by steam when it condenses into liquid water you can roughly measure in your class-room. Take a vessel with some water in it (a small copper boiler is best), arrange it over a bunsen burner, and connect it by means of glass tubing with another vessel containing water, as in the picture, so that if you heat the water in the copper vessel to boiling, steam will pass through the glass tube into the water in the other glass vessel.

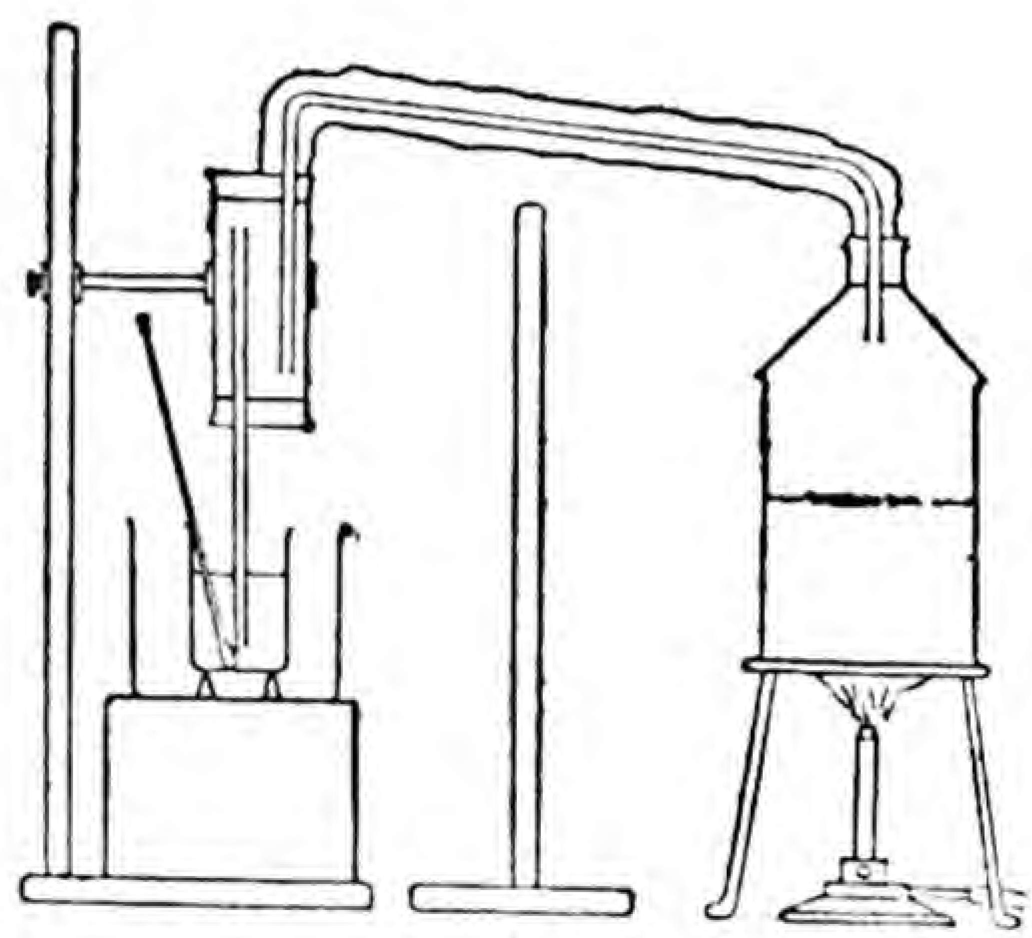


FIG. 72.—*An experiment to show how much heat is given off by steam when it condenses to liquid water.*

To prevent too much of the steam from cooling and condensing as it passes along from one vessel to the other, strips of flannel must be wound round the glass tube. And to prevent any water which may have condensed in the tube from passing into the second vessel, an arrangement called a separator must be rigged up as shown in the figure: any condensed water will stay at the bottom of the separator, and only dry steam will be able to pass on. You should have a screen between the burner and the second vessel in order to prevent the flame heating up the water in this vessel.

Weigh the second vessel empty. Then put some water in and weigh again; the difference between the two

weighings will give you the weight of the water. Heat the copper vessel until it boils, and after letting steam escape into the air from the end of the tube for a few minutes, put the end of the tube into the second vessel, after previously taking the temperature of the water in it. Go on with the experiment until the temperature of the water into which the steam is passing has been raised about 20° C.; then remove the second vessel and weigh it again. From this last weighing you can tell how much steam has been condensed into water during the experiment; and from this and the rise in temperature of the water you can calculate how much heat a given weight of steam gives off in condensing.

The usual unit for measuring heat is called a *calorie*: it represents a "gram-degree"—the amount of heat needed to raise the temperature of 1 gram of water by 1 degree Centigrade. Accurate experiments show that 1 gram of steam gives off 539 calories in condensing to water, or enough heat to raise the temperature of nearly five and a half times its own weight of liquid water from freezing-point to boiling-point. The same amount of heat is needed to turn 1 gram of water at boiling-point into steam. You can see that it takes a great deal of heat-energy to turn the liquid water into the gaseous steam. This amount of heat does not show in the temperature of the steam; so we call it *latent heat*, which means heat that hides itself away. When steam turns back into water, it gives up its latent heat again.

But it is not only at boiling-point that water can turn into vapour. Everyone knows that a saucer of water will dry up if just left in a room at ordinary temperatures (see Book I, p. 129). Some of the liquid water is turning into vapour, which is then carried away by the air. When

the water is cold it does not vaporize nearly so vigorously; as it gets hotter it turns into vapour more and more easily, until at boiling-point the pressure of the vapour becomes equal to that of the air, and it streams away freely. And, of course, the rate at which water dries up by turning into vapour will depend upon how damp the air already is. If the air is quite dry, the water will be able to turn into vapour, or *evaporate*, as it is called, quickly; but if it is moist it will be more difficult for the water to evaporate, and it will dry up much more slowly. In fact, the air may already have so much water vapour in it that it cannot hold any more; then we call it *saturated*.

The amount of water vapour needed to saturate air is not always the same; the hotter the air, the more water it can hold. Dew is a result of this fact. At night, the temperature falls and cools the air; the air cannot carry so much water vapour, and so some of the vapour may have to turn back again into liquid water—in other words, dew forms. But whenever water turns into vapour, whether at boiling-point or at ordinary temperatures, heat is needed to change it from the liquid state into the gas state.

At whatever temperature water happens to be, it takes heat to turn it into vapour. People who live in hot countries take advantage of this by keeping water in jars made of unglazed earthenware, or in bottles made of canvas. These are porous—that is to say, they have tiny holes in them through which water can ooze out very slowly. As the water oozes out, it evaporates into the warm air in the form of water vapour. But in transforming itself from liquid water to vapour it uses up heat. It takes a good deal of this heat from the jar and the water inside it, and so the water, though a little of it is lost as vapour, stays much

cooler than if it were in a water-tight vessel of glass or metal. As we shall see in the next chapter, our bodies keep themselves cool in hot weather in a way that is very similar to this. If you want to keep drinks cool in a glass vessel, wrap the bottle in a wet towel, and set it in the sun; you can think out for yourselves why this is better than keeping it in the shade.

Just as it takes heat to turn water into vapour or steam, so it takes heat to turn ice into water. You all know that when a thaw sets in after a long frost the ponds may still be covered with ice even after several quite warm days. Of course, the ice is taking up heat from the air all the time; but so long as there is any ice left, its temperature stays at freezing-point—0° C. or 32° F. The same thing happens when people put lumps of ice in cold drinks like lemonade. So long as the ice is melting it is taking up heat from the lemonade, and so keeps it cold for a long time.

The same sort of thing, but on a grand scale, happens in some parts of the world. Where there are mountains in the polar regions, there is so much snow and ice that, though a great deal of it is melted by the sun during the summer, it cannot all be melted away, and there is always a layer of it covering the ground. The temperature of this layer can never rise above freezing-point, and so the temperature of the whole region stays very low. Besides, clean snow and ice are very good reflectors of light and heat. So a great deal of the light rays, instead of heating the snow, are reflected back again into space. You can be badly sunburnt by the light reflected from snow. If the snow were covered with a layer of soot, it would reflect very little light and heat, and would melt much quicker.

In other parts of the polar regions, like the flat, low plains of Northern Greenland and Northern Siberia, the layer of snow and ice is not so thick, and in most places the sun melts it right away before the end of the summer. Then the heat of the sun's rays can warm up the soil, instead of being used up in melting the snow; as a result, the temperature of these polar plains gets quite high towards the end of summer. The mountainous parts of the polar regions are rather like a cold drink with plenty of ice in it, while the polar plains are like one with only a tiny piece of ice.

Melting-Points and Boiling-Points

Above water, at ordinary temperature, there is some water vapour. The water vapour exerts a small pressure; this we can show by filling two glass tubes closed at one end with mercury and inverting them at their open end in mercury. The mercury in the tubes will stand about 30 inches above the mercury in the vessel: it is supported by the pressure of the air, as explained in Chapter V of Part I.

If we now put a drop or two of water in one of the tubes (it will float up through the mercury if introduced at the open end of the tube), the mercury level in this tube will fall a little. This is because of the pressure of the water vapour in the space above the mercury. This pressure increases as the temperature is raised, as can easily be shown by warming the water in the tube with a burner, when the mercury will fall in the tube. If the water boils, the mercury will fall until it is at the same level inside and outside the tube. This shows that when water is boiling, the pressure of the water vapour is the same as the pressure of the air.

To understand what is happening we can think of a number of people shut up in a room, which we can call "water-people," the room being closed by a door against which a number of other people are pressing from outside; these outsiders we can call "air-people." If the water-people are not very energetic, occasionally one may give a lucky push and escape, but on the whole only one now and then will get out. This corresponds to cold water, which exerts only a small vapour pressure. When the temperature is raised to boiling-point, the water-people will be pressing as energetically as the air-people outside, or, in other words, the vapour can escape freely and the water boils.

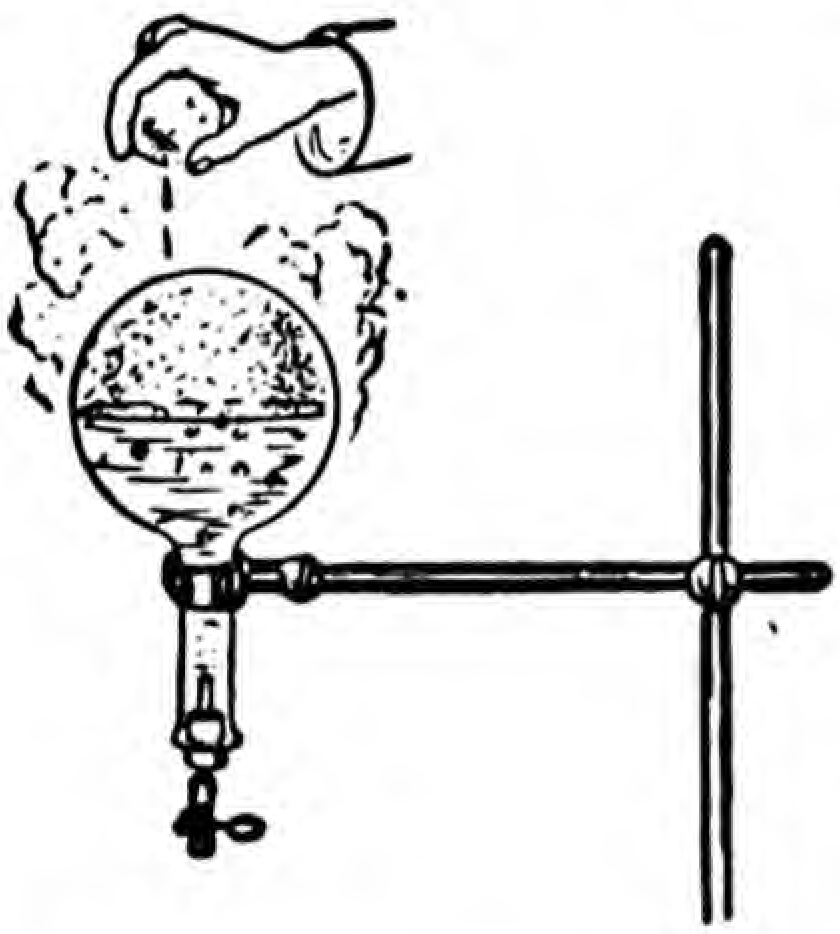


FIG. 73.—*Squeezing cold water on to a flask full of water which has just been boiling lowers the pressure in the flask and makes the water boil again.*

We should therefore expect that the pressure of the air outside has an effect on the temperature at which water and other liquids boil. This is the case. If the air-pressure is lower than usual, it is easier for the water to escape in the form of vapour, and so at low air-pressures water boils at a lower temperature than usual. If you boil water vigorously in a flask, so that all the air is driven out by steam, quickly close its outlet with a clip as in the picture, and turn it upside-down and then squeeze cold water out of a sponge on to it, the water inside will start boiling again. This is because the cold water makes the steam, with which the upper part of the flask is filled, condense, so that the pressure is lowered. The water is still hot enough to boil at this lowered pressure, although

it is too cool to boil under the full pressure of the atmosphere. In the same way, if you attach the flask which has just been boiling to an air-pump, pumping air out of it will soon make it boil violently again, although it has had time to cool down a good deal.

In the same way, the boiling-point of water gets lower as you go up a mountain. The higher you go the less air-pressure there is. If you go up really high, it is no good taking potatoes, as you will not be able to cook them properly; you can put them into boiling water, but the water will be boiling at such a low temperature that it does not soften the potato enough for you to enjoy eating it. The Mount Everest Expedition camped for months far above the height at which they could cook an egg properly, for the white of an egg will not "set" below about 83° C., and this is the boiling-point of water at a height of only about 18,000 feet. But in return for not being able to cook various things in the high mountains, you can find out how high you are by boiling some water and taking its temperature. This method, however, is not so accurate as the method described in Book I, p. 122, by taking the air-pressure directly.

On the other hand, if the air-pressure is higher than usual, it is harder for the liquid water to come out into the air in the form of vapour, and water will only begin to boil when the temperature is above 100° C. In the boilers of many kinds of steam-engines the pressure is 300 lbs. to the square inch, which is 20 times the pressure of the air outside. At this pressure, water will not boil until a temperature of 214° C. is reached, instead of at 100° C. In some modern turbine engines, the pressure is 500 lbs. to the square inch, and the boiling-point of water 243° C.

We saw in Book I that gases such as air can be turned into liquids by making them very cold, and solids like steel can be melted and turned into liquids by making them very hot. In fact, whether a substance appears in a solid or a liquid or a gas form depends simply upon the

FIG. 74.—*Above, Mauna Loa, a volcano in the island of Hawaii, in eruption: streams of lava, from which steam is rising, are pouring down its sides. Below, a stream of lava after it has cooled down.*

temperature and pressure at which it happens to be. There is a picture of liquid metal in Part I (Fig. 36).

The temperature of a place is very important in deciding what animals and plants shall be able to live there. Indeed, if the average temperature of the earth were only

a little colder or a little hotter, no life could exist on it at all. If it were below 32° F., there would be only ice in place of liquid water, and if it were above boiling-point, all the water in the sea would boil away into vapour.

If you go down into the earth, in a mine, for instance, the temperature gets higher the deeper you go. The deepest mines in the world reach a depth of about a mile, and the temperature of the rocks in such mines may be as high as 150° F. (and so men can only work if a strong current of cool air is blown through the workings). Very deep down in the earth the temperature is enormously high, so high that even solid rock is melted. In volcanoes this liquid rock comes to the surface, and pours out as what is called *lava*. Rivers of lava flow down the mountain-side, but soon cool and turn solid.

All the other planets, except Mars, are either too hot or too cold for any living things, at least any living things of a type at all like those found on the earth, to exist. We do not yet know if any life exists on Mars. The temperatures of all the stars that we can see are much too high for life; nor could life exist in the space between the stars. Some stars may perhaps have planets circling round them, and some of these planets may perhaps have life on them. But we can be certain that life cannot exist except in a very few places in the universe.

CHAPTER V

HUMAN TEMPERATURE: HUMAN HEALTH

Ventilation—Air and Sun—Different Kinds of Food—Health and Food—Exercise and Sleep—Cleanliness and Health

NOW we can come back to the human body and its temperature. We are all the time making heat by the chemical processes of slow burning that go on inside us, especially in our muscles when we take exercise; and we are all the time losing heat to the outside world.

So if our temperature is to be raised it can be done in two ways: either by preventing heat from leaking away from us as fast as usual, or by speeding up the rate at which heat is generated inside us. And, similarly, we can lower our temperature either by arranging for more heat to be lost at our surface, or by slowing down the production of heat inside our bodies.

Let us think first of the ways in which we can alter the amount of heat which we make. When it is very hot we do not feel like eating a great deal; consequently there is not so much fuel to be slowly burnt inside us, and not so much heat can be generated. Besides this, the chemical processes themselves are altered by messages from the nervous system, in a way we do not yet altogether understand, so that they are slowed down and less heat is produced. Finally, when it is hot, we generally do not feel like taking violent exercise; and as exercise generates heat, for this reason also we do not make so much heat as usual.

On the other hand, when it is cold we feel like eating more, so that we have more fuel available for heat production. We also feel like taking exercise: if you have to wait about on a cold day you will find yourself stamping your feet, beating your arms, or running up and down in an attempt to keep warm. Finally, through the nervous system, the heat-generating processes themselves are made more active. It may surprise you to know that shivering is one of the ways in which this is done. Most people think of shivering as a chilly activity. So it is, in a sense; it only happens when we feel cold. But what it does is to prevent us from getting still colder. When we begin to be thoroughly chilled, the central nervous system sends messages out to our muscles which make them contract slightly but quickly in the way we describe as shivering. The contractions use up food-material as fuel; and its combustion produces heat. So when we shiver we are making more heat than if our muscles were quite quiet.

Now let us think about the ways in which we can alter the amount of heat which we lose at the surface of our body. We have one very ingenious way of dealing with this, by regulating the amount of blood sent through the skin. You all know that on a cold day your skin feels cold. What is more, it *is* cold. It is colder than the parts deeper inside you, because less blood is being sent through it. More of your warm blood is being kept away from the surface, less of it is being allowed to circulate through your skin, where it can lose some of its heat to the outer air, and so you lose less heat than you otherwise would.

This is done by means of the muscles in the blood-vessels. In Chapter II we explained how a blood-vessel has a thin coat of muscle all round it. When this contracts it narrows the blood-vessel, so that less blood can

flow through: when it expands, the blood-vessel broadens and lets more blood pass. Instead of there being taps on all the little blood-pipes to regulate the amount of blood flowing through them, the pipes themselves grow bigger or smaller.

What the muscles of the blood-vessels do depends on messages from the central nervous system. When you are cold the blood-vessels near the skin are narrowed, while those deeper down are opened up. When you are hot the reverse happens: the blood-vessels near the skin are opened up, plenty of blood can flow through them, and the skin gets warm.

FIG. 75.—*A robin redbreast on a warm day and on a cold day.*

This arrangement regulates the amount of heat near the surface of your body. In addition, there are ways for regulating the speed at which this heat shall be lost. Most animals with a constant temperature have a thick coat of hair or feathers, and they can use this to adjust the amount of heat which leaks away. If you look at a small bird like a robin redbreast while it is sitting quiet on a cold winter's day, you will see that it looks all puffed out. This is because it has moved its feathers, by means

of little muscles attached to their roots, so that they stick out more than usual. In this way it has entangled a great deal of air in the spaces between the feathers. As we saw in the last chapter, air, compared with anything solid, is a bad conductor of heat. So when the robin fluffs out its feathers, it loses less heat than usual. On a warm summer's day, on the other hand, it will keep its feathers pressed tight against its skin, and so heat can leak out much more easily. The same sort of thing happens with many hairy animals, especially those with thick fur living in cold climates.

We have no fur or feathers, so we cannot do this. But we can produce the same result by changing our clothes. On a hot day it is pleasant to wear as little as possible; the air can get to our skin and take heat away by convection. But on a very cold day we wear several layers of clothes, so as to imprison several layers of air between our skin and the outside world, and we button our clothes up tight to prevent these layers of air from losing heat by convection.

Fur entangles a great deal of air and so keeps us beautifully warm. That is why people who can afford it wear fur coats and fur gloves. But the most important thing of all in great cold is for clothes to be windproof. In the arctic, Eskimos wear only one garment; but it is made of sealskin with the fur inside, it is tied tight round the neck and wrists and legs, and is windproof. Polar explorers nowadays generally wear special windproof overalls which are much lighter than fur clothes.

Finally, there are special arrangements for rapid cooling—in other words, for losing heat more quickly than usual—when we are too hot. One way is by direct cooling with air. This is what happens with dogs. When a

dog is very hot it opens its mouth and pants with its tongue hanging out. In this way it quickly gets rid of a great deal of heat by heating up the air it takes into its lungs and then breathing it out; it also loses a good deal of heat through the surface of its tongue and of the warm inside of its mouth. Besides this, its tongue and the inside of its mouth are moist, and so are cooled as water evaporates from them; but it loses heat mostly by direct cooling with air.

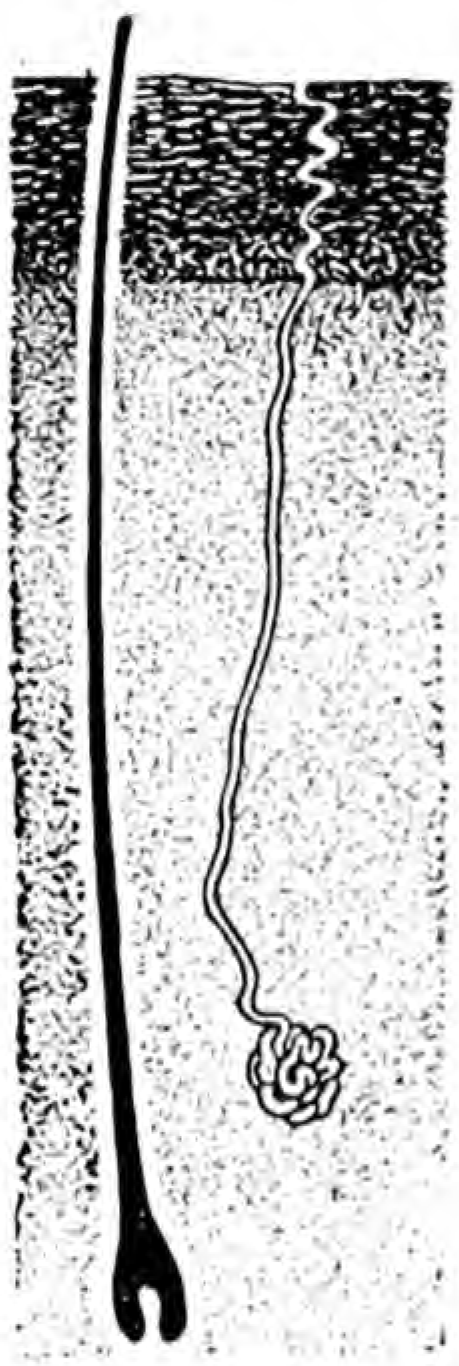


FIG. 76 —*A sweat-gland with its little tube, along which the sweat escapes on to the outside of the skin. The hair on the left shows how much the picture is magnified.*

We can get rid of some heat in this way, but we depend mostly on our power of sweating, or perspiring, as it is sometimes called. Embedded in our skin are thousands of microscopic sweat-glands. Each of these is a tiny tube opening to the outside, whose business it is to pour out their secretion, consisting of slightly salty water, on to the surface of the skin. When we are cold they stop making and pouring out their secretion; when we are very hot they pour out great quantities, which may accumulate in drops of sweat or perspiration.

We have just seen that when liquid water turns into vapour it uses up a great deal of heat in the process. This is why it is so dangerous to sit about in wet clothes if there is any breeze or draught, even if the day is warm. The moving air takes away some water vapour from our clothes; the water in the clothes forms more water vapour, which is again carried away, and so on until the clothes are dry. This rapid evaporation takes place largely at the

expense of heat from the skin, which becomes rapidly cooled, and we may catch a chill. Just the same kind of thing happens when we sweat. As the sweat evaporates it takes up heat from the skin. If it evaporates quickly—for instance, if we have few clothes on and a wind is blowing—our skin gets quite chilly. That is why it is a good thing to put on a sweater or a coat after any violent exercise which has made us perspire.

When we are very cold we do not sweat at all. But often when we are moderately warm, although there may be no drops of sweat on our skin, yet we are sweating slightly. The perspiration is evaporating as soon as it gets on to the surface of the skin, before it can form drops, and so is cooling us all the time, even though it is invisible. We saw in the last chapter how drinking-water can be kept cool in hot climates in a rather similar way.

Sweating can keep us cool at very high temperatures, provided the air is dry. In a Turkish bath, for instance, some of the rooms are made very hot in order to bring on sweating. The actual temperature of the hottest room is generally almost as high as that of boiling water; but people can sit in it without coming to any harm, because the dry heat makes the sweat pour out of them, and the rapid evaporation of the sweat keeps them cool. In fact, men have actually stayed in an oven while meat was being cooked in it, and have only come out when their hair began to singe! If they had not been able to sweat they would have been cooked too, but by sweating prodigiously they were able to keep themselves cool enough to be undamaged. They have to drink a great deal of water before such an adventure, so that there may be a good supply of moisture for sweat.

The amount of water which the sweat-glands can

secrete out of the blood on to the surface of the skin is very large. There is a record of an English coal-miner who produced 18 lbs. of sweat (nearly 2 gallons) in $5\frac{1}{2}$ hours.

But in air which is not dry, sweating cannot keep us cool so easily. It is harder for the sweat to evaporate, and it is the evaporation which cools us. If the air is saturated with moisture—in other words, so full of water vapour that it can hold no more—then sweat may pour off us, but none of it can evaporate, and it does us no good. If a man is put in air saturated with water vapour at a temperature higher than the normal temperature of his body, his own temperature will rise, and he will become very ill and may even die, if he stays there any length of time.

So on very muggy days and in parts of the world like the Gold Coast, where the climate is hot and steamy, people feel much more uncomfortable than they do even at much higher temperatures where it is dry.

Luckily the outside air is rarely quite saturated. But even when it is not fully saturated people suffer great discomfort when there is no wind. For then the perspiration itself, as it evaporates, saturates the air just round the skin, so that hardly any further evaporation can take place. That is the reason why a breeze is so refreshing to us on a hot day. The breeze itself is not particularly cool, but it is all the time bringing new unsaturated air to evaporate our perspiration, and that is what makes it feel cool.

We have now described the different ways in which the body can be heated or cooled. These must be balanced against each other if our temperature is to stay steady. This balancing or regulating is done by the nervous

system. There is a part of the brain which is exceedingly sensitive to changes in the temperature of the blood flowing through it. If the temperature of the blood is a fraction of a degree lower than normal, this part of the brain sends out messages which put into action the processes which generate more heat and prevent us losing it as rapidly as usual; the opposite happens when the blood is the least bit warmer than normal.

Thus most of the arrangements for controlling temperature in our bodies are automatic (which means that they work by themselves) and self-regulating; our will has no effect on them. It is interesting to compare them with the automatic arrangements which men have invented for regulating temperature in places where a steady temperature is wanted. This is necessary in egg incubators where fowls' eggs are hatched artificially instead of being put under a hen: they will not hatch if the temperature varies more than a very few degrees. Again, it is often very important to have a constant temperature for scientific experiments on living animals and plants; many bacteria, for instance, grow best just at blood-heat. Such experiments are done in an incubator heated with gas or electricity; if the temperature gets too high, the gas or electric current is automatically cut off. One arrangement for doing this is to have a little metal capsule filled with a particular kind of fluid in the

FIG. 77.—*An incubator for keeping eggs at a constant temperature until they hatch.*

incubator. When the temperature rises, the capsule is expanded by the boiling of the fluid inside it. On the capsule rests the bottom of a metal rod, and the other end of the rod pushes against a lever which shuts off the gas or breaks the electric current. So when the capsule expands the rod is pushed up and the heat is shut off.

Some household heating systems have arrangements of this sort. When the temperature of the water in the pipes rises too high, a temperature-regulating device is set in action which brings the damper down, so that there is less draught and the fire burns more slowly. If the temperature falls too low, the damper is pulled up, and in some modern systems extra coal is automatically let into the furnace.

FIG. 78. — *Hibernation. A dormouse during its winter sleep.*

It is interesting to know that other kinds of animals have the power which we have of regulating their temperature. As we have mentioned, all birds and mammals are able to do this. Birds, by the way, have much higher temperatures than other animals, ranging to 105° F. and over, which would be fever-heat for us. In some animals the power of regulating temperature is not very strongly developed. For instance, creatures like dormice and marmots, if the outside temperature gets very low, are not able to keep their own temperature very high, but get quite cold themselves, and go into the

hibernating condition, in which their breathing and all other vital activities are slowed down almost to nothing.

Young birds and mammals, especially those kinds which are hatched or born naked, cannot at first regulate their temperatures. That is why, in birds with naked young, like sparrows and thrushes, the mother-bird must sit on the nestlings most of the time, for otherwise they would die of cold. By the time they have developed their feathers they have also developed arrangements for regulating their temperature.

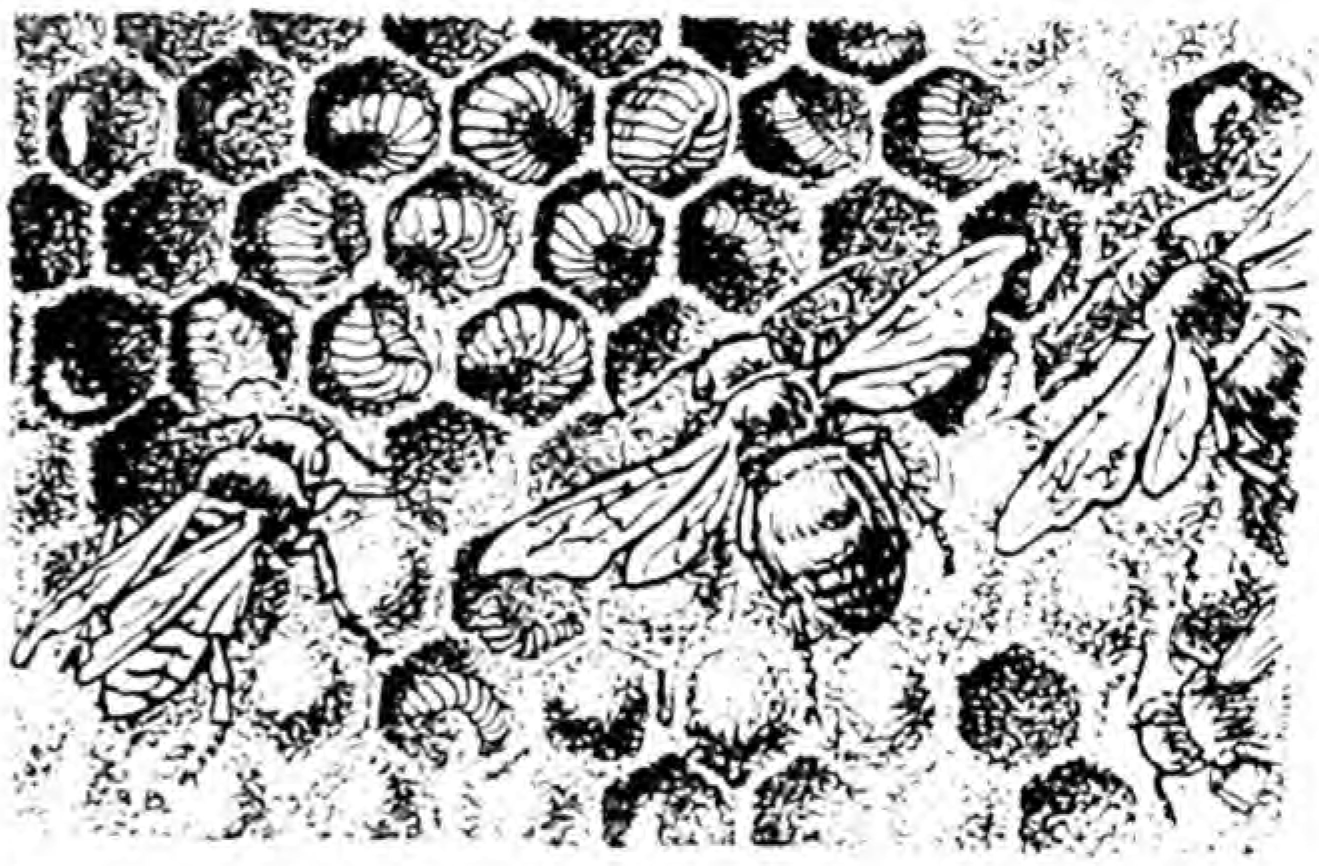


FIG. 79.—*A piece of comb in a bee-hive with young bees in it. The cells with growing grubs in them are left open so that the grubs can be fed. When the grub turns into a pupa, the cell is sealed up. Worker bees are keeping the comb cool and ventilating the hive by making a current of air with their wings.*

Very few other animals have this power. The hive-bee is the most interesting example. Single bees do not regulate their own temperatures, but all the bees in a hive taken together manage to regulate the temperature of the hive. In the spring and summer, if it is cold, the worker bees gather on the surface of the combs in which the little bee-grubs are growing up and crawl quickly about, thus raising the temperature by means of the heat given out by their muscles. If it is too hot, gangs of bees stand in the passages of the hive and ventilate the place by using their wings to make a current of air. By these means the temperatures at which the grubs grow up is

kept very steady at nearly blood-heat, usually between 93° and 95° F.

In the winter there are no grubs growing up, and the temperature of the hive is not kept so high or regulated so carefully. But some precautions must be taken that it shall not fall too low so that the bees get frozen. So, if the temperature of the hive falls below about 55° F., the bees gather together in a dense mass and crawl about actively; this raises the temperature of the crowd of bees. The temperature of the bunch may rise from 55° to 75° F. in less than an hour.

Human beings not only have arrangements in their bodies for regulating their own temperature, they also, like the bees, have ways of regulating the temperature of the places where they live. At first these methods were very simple—just lighting a fire when it was cold, or getting servants to make a draught with big fans when it was hot. Today the methods are wonderfully improved. With central heating, houses can be kept pleasantly warm even in the coldest winter, and with proper arrangements for ventilation fresh air can be drawn in without making a draught. With the most modern heating systems the temperature can be automatically regulated to within a few degrees. In hot climates the improvement has not been so great, although electric fans help a great deal. The next step will be to make central cooling systems, on the same plan as central heating systems, but with a refrigerator instead of a boiler. With these, white people could live much more comfortably in the tropics. Already in various countries some theatres and cinemas are cooled in summer.

We have seen how men have invented tools and machines which give them extra power beyond what they

have in their own muscles, and instruments which act as artificial sense-organs to give them extra knowledge. Now we see that they are better able than any animal to regulate the surroundings in which they live. In their houses they provide themselves with an artificial climate, much less trying than the climate in the open air. Without their being able to do this there could be no civilization.

Ventilation

So far, when we have been talking about the body, we have been considering the way it works when it is healthy. However, in spite of all the wonderful self-regulating arrangements which exist in the body, it is quite easy for its machinery to get out of order. Something may happen to it from outside: disease-germs may get into your system and make you ill, or you may get hurt in an accident: or you yourself may treat it badly and upset its workings: you may eat and drink too much, or eat and drink the wrong things, or overstrain yourself, or not take enough sleep.

If you neglect a motor-car, and run it in a careless way, it is bound to get out of order quicker than if you understand its workings and treat it properly. The human body is much more complicated than a motor-car, and it is very important to know how to treat it to keep it in the best possible working order.

We will begin with ventilation and fresh air and similar subjects, for these have a good deal to do with the power we have of keeping our temperatures steady, of which we have just been speaking.

Everybody knows that in a crowded, stuffy room with bad ventilation people soon begin to feel uncomfortable. It used to be supposed that this was because there was too

little oxygen and too much carbon dioxide in the room, owing to the breathing of all the people in it. Now, however, we know that this is wrong. Carbon dioxide has very little bad effect until it is present in amounts far greater than any which we find even in a very crowded room after it has been packed with people for several hours. There is always enough air leaking in through cracks round windows and doors to keep the amount of oxygen from falling much. It is worth remembering that high up in the Alps, where people go for their health, there is much less oxygen in each breath (owing to the air being more rarefied because the pressure is lower) than in the stuffiest hall in a town near sea-level.

Nor are there any poisons in air which has been breathed by a crowd of people. If there are disease-germs in a crowded room, the only way to clear them out is by ventilation; so it is easier to catch a cold or a sore throat in a stuffy room than in one which has the windows open or is properly ventilated in some other way. There is often an unpleasant smell when a lot of people are crowded together, especially if they are not very clean. This is not poisonous to your body, though it may be unpleasant enough to make you feel uncomfortable. But the chief reasons why stuffiness and crowds are bad for you are the heat and the moisture of the air.

People are producing heat all the time, so when there is a crowd of people in a room with the windows shut the temperature of the room is bound to go up. If there are a lot of lights in the room as well, they will raise the temperature still more. Another thing which people do, as we saw in the first chapter, is to breathe out more water vapour than they breathe in. So the air in a crowded, stuffy room is all the time getting damper as well as hotter.

If the windows are all shut there will be very little movement of air in the room. The result is that in the room we soon get conditions of a sort which, as we have seen, is very difficult for our bodies to deal with. The air is hot, so that it is difficult for our bodies to lose heat to it directly; it is wet, so that it is difficult for our bodies to cool themselves by evaporating sweat; and it is still, which makes both ways of losing heat harder. This is a great strain on our body machinery, and may make us quite ill.

Electric fans make some difference in a crowded room, but they only move the air, and do not cool it or make it less moist. It is much the best to have some arrangement for getting rid of the hot, moist air, and bringing in cooler, drier air in its place. This is called ventilating the room. Opening the windows is the simplest method of ventilation, and is often the best. But it is not always satisfactory when it is very cold outside, or when it is raining. So rooms are often built with air-inlets and air-outlets in the walls. The outlets are put just under the ceiling in such a way that the heated air will rise and escape through them; and the inlets are put lower down. In some up-to-date halls and theatres, the ventilation is by forced draught, and the air is sucked out by fans. Sometimes the incoming air is made cooler by being run through a refrigerator, and usually there is an arrangement for filtering dirt and dust out of it.

Besides providing cooler and drier air, ventilation carries away any disease-germs which may be present. A man with a bad cold is much less likely to give his cold to other people in a well-ventilated room than in one which is stuffy.

Air and Sun

Our bodies work best when they are able to lose heat fairly rapidly, but not too rapidly to get really chilly. The loss of heat acts on us rather like the draught in a fire. We have to make more heat to take the place of what we are losing, and so we take more exercise, digest our food better and use it quicker. This power improves with practice. Everybody knows that muscles grow bigger and stronger when they are regularly used: if you get into training by taking exercise regularly, a little more each day, you find that you can soon quite easily do things which before would have quite exhausted you. The heat-regulating machinery in your body improves with practice in the same sort of way. If you have been used to wearing a great many clothes and to living in hot, stuffy rooms, you will feel very cold if you *suddenly* try to wear much less and to keep the room cool, and if you are not careful you may catch a chill. But if you go about it gradually, you will find that your body learns how to produce heat more quickly to make up for what you are losing, and that in a week or two not only do you not find it chilly to wear less and live in a cooler room, but you feel better and warmer in yourself.

The skin works best of all when the air around it is cool and dry, and when it is exposed to bright sunshine. The sun's rays do something to the skin which we do not altogether understand, except that what they do is good for us, provided we do not expose ourselves to the sun too long, especially at first. Too much sun can give us quite a bad burn, and even make us quite ill. In the mountains in Switzerland the sun is usually bright and the air cold. Delicate children who are sent there to get better are

made to expose more and more of their bodies to the sun and air every day, until at length they can go about comfortably, even in winter, when there is sun and not too much wind, with practically no clothes on; and it is found that this does them good.

FIG. 80.—*A lady's bathing-dress in 1890. Modern bathing-dresses are much healthier as well as more comfortable, because they expose more of the skin to the sun and air.*

FIG. 81.—*In tropical countries sun-helmets are used to protect the head and the back of the neck from the sun.*

Sunshine is very important for health. If it is too strong it is bad for you. That is why white people in tropical countries like Africa wear sun-helmets to prevent themselves getting sunstroke. That, too, is why natives of tropical countries are black or brown, because the dark colour in their skins absorbs the sun's radiation and prevents it from getting through to the living tissues under the skin and damaging them. On page 32 of the "Practical Handbook to Book I" there is a description of an experiment about the absorption of heat by black surfaces. Most white people, if they are out in the sun much, get sunburnt

and tanned, which means that they make brown colouring stuff in their skin. It is the same kind of colour that a black man has in his skin, only there is not so much of it. Its use is just the same as in a black man—to prevent too much of the sun's rays from getting through the skin.

However, a certain amount of sunshine is very good for you. Not only is it good for your skin and for your general health, but it keeps away certain diseases. There is a disease called rickets, in which children's bones do not grow properly. It used to be thought that this was due only to wrong kinds of foods, but we know now that lack of sunlight also has a great deal to do with it. It is very difficult to get rickets if you are out in the sun a good deal.

Then the sun prevents disease in another way. Bright sunshine kills most kinds of bacteria, including many disease-germs. So a bright airy house will be healthier than a dark one.

Different Kinds of Foods

There are two chief purposes for which you need your food. One we have already spoken of in Chapter I: it is to serve as fuel. The food-material joins with oxygen, and this slow combustion provides energy for warming our bodies and for moving us about. Besides this, there is another main purpose. When we are young we are still growing. This means, of course, that we are building new living material in our bodies; and the new material must come from our food. Even when we are grown-up and have stopped growing, there is a good deal of wear and tear in our bodies. Parts of the living machinery get scrapped and have to be replaced. For instance, though you yourself stop growing, your skin never stops

growing. A layer of it which is buried below the surface is all the time turning part of itself into dead horny material; this acts as a protection for the delicate living parts below, and eventually flakes off. If you have an arm or a leg bandaged up for a long time, you will find when the bandage is taken off a good deal of this flaky material, which is called scurf or scarf-skin. Usually it drops off in tiny flakes and is not noticed, but when there is a bandage over it, it is kept in place. The buried layer of the skin must be built up from the food all the time to make up for the horny material it is losing. Even when no material is scrapped, as with the skin, the living machinery is all the time breaking down here and there, and needing to be repaired; and the material for this must come from the food too. So, in addition to food for fuel, we need food for body-building.

Now the fuel foods need only have in them carbon and hydrogen (though, like sugar, they may also have some oxygen). But the living material of the body has a good deal of nitrogen in it as well as carbon, hydrogen, and oxygen; so the body-building foods must contain some nitrogen.

The ordinary body-building foods are what are called *proteins*. White of egg is a protein, and so is most of cheese, and most of lean meat. Fish provides plenty of excellent protein, and is generally cheaper than meat. Nuts have a great deal of protein in them, and both milk and bread have a good deal.

The foods which can only be used for fuel are of two main kinds. The fuel foods of one kind are called *carbohydrates*, which comes from two words meaning carbon and water, because they are made of carbon, together with hydrogen and oxygen in the same proportions as they

are found in water (see Part I, Chapter IV). We shall talk more about carbohydrates in the next chapter. Sugar is carbohydrate food, and so is starch. We are used to thinking of starch merely as a white powdery stuff used for stiffening collars and shirts; but it is extremely important in the lives both of animals and plants. It is chemically very like sugar; the chief difference is that all kinds of sugar are easily dissolved in water, while most kinds of starch will not dissolve. There is a good deal of starchy food in bread, and a great deal in potatoes. The other chief kind of fuel food is provided by fats and oils, like butter, and the fat in meat, and lard, and olive oil, and seal-blubber (which is the only kind of pure fuel food which the Eskimos can get). Both carbohydrates and fatty foods have carbon and hydrogen in them, but the fats and oils have nothing else, while the carbohydrates have oxygen as well.

In body-building foods, too, there is a good deal of material which can be used to join with oxygen, and much of this, as well as carbohydrates and fats, is used for fuel. Flesh-eating animals can get all their fuel out of proteins; for instance, you can keep a dog or a lion alive and healthy on nothing but raw meat. But no animal can grow or repair itself without some body-building foods.

Besides these two main sorts of food there are various extras which are in their way just as important. Water is one. Water is part of every bit of us. Our living machinery must have just the right amount of water in it (about three-fifths of your weight is nothing but water). A current of water is all the time passing through us. If we were not losing water all the time through our lungs and our kidneys and our skin we could not breathe, or flush waste material out of our system, or keep our temperature from

going too high in hot weather. A man who can get no water dies much more quickly than a man without food.

Then there are various different kinds of salts that are necessary. Usually, almost all of these are found in ordinary foods; but there are parts of the world where there is not enough of one or other of them, and then they have to be brought in from outside. For instance, up in the mountains of India and Burma, there are many places where there is not enough of many kinds of salt. Here salt has

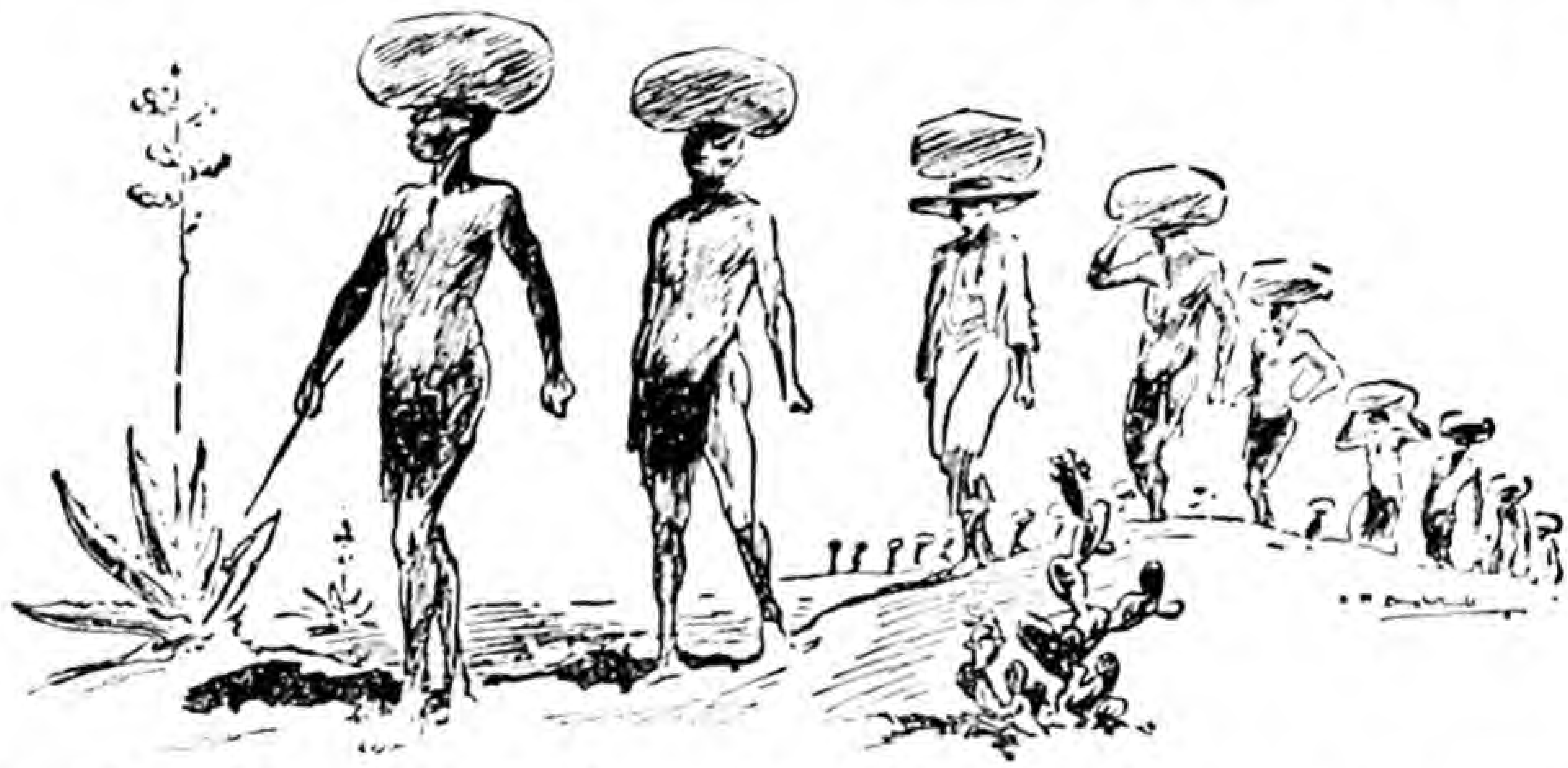


FIG. 82.—*A salt caravan in Central Africa. The loads are generally about fifty pounds.*

to be brought up from the coast, hundreds of miles away, and the natives will pay a very high price for lumps of ordinary sea-salt. There are also many parts of Central Africa where salts are precious and have to be brought long distances. Then, in certain regions, like parts of Switzerland and of the Middle West of the United States, there is not enough of a special kind of salt which has a substance called iodine in it. In these regions, people often get a disease called goitre, in which their necks swell, and they grow rather fat and sluggish; and sometimes baby pigs are born without hair, and die. This can be pre-

vented by giving tiny amounts of salt with iodine in it with the food.

Then there are some other food extras which are called *vitamins*. They, like various salts, are necessary if the body is to stay healthy, and to be able to use its other food-materials properly; but only tiny amounts of them are needed. They are mostly found in various fresh foods, like fresh milk, fruits, green vegetables, eggs and so on, different ones in different foods.

Health and Food

The first thing with food is obviously to have enough of it. Most people get enough food for health, though sometimes in some parts of the world there are terrible famines in which thousands of people die of hunger, like the Russian famine in 1922, or the famines that come from time to time in China, when in a large stretch of country the crops fail, and there is no way of sending enough food from outside.

The next thing is not to eat too much. Over-eating is in the long run very bad for people. It makes them sluggish and stupid, and gives their digestive systems and their kidneys too much to do, so that they often end up by being unwell all the time. In civilized countries, for most people the danger of eating too much is far greater than the danger of eating too little.

The third thing about food is to have a properly balanced diet, not one with too much of one sort of food and too little of another. That we shall speak about a little later.

There are some other things about food which are important, although they do not have to do with the way the food-material is used in the body-machine. For instance,

some of the materials in food cannot be digested and passed into the blood from the intestine. These useless materials are got rid of from your intestine when your bowels move. It is very important to get rid of this food-rubbish or waste material regularly every day, because it makes poisonous substances, and if it is kept in your intestine too long, these will get into your blood and make you tired and ill. One way of helping to make sure of this is to eat a good deal of bulky food, like green vegetables and fruit and coarse cereals. This kind of food is often called roughage; much of it is not digested, but it helps your bowels to be active, and to get rid of the rubbish and waste they have inside them.

Another thing about food is that it should be cooked so as to taste nice, and be well served. Not everything that tastes good is good for us, but when things taste and look nice, and we enjoy them, messages are sent along nerves from our brain which make our digestions work better. Also food should not be too sloppy so that we swallow it without chewing it. For one thing, we taste our food better if we bite it up properly. For another, some foods, like those with starch in them, can be partly digested by the juices of the mouth; if we bolt them, we do not give the mouth juices a chance of doing their work.

All the different kinds of food we eat, taken together, we call our diet. As regards diet, we can be sure of eating in a healthy way if the food we eat is fresh and is of many different kinds. There should be some protein food, like meat or fish or eggs; there should be some carbohydrate food, like sugar or potatoes; there should be some fatty food, like butter; there should also be some foods which are mixed, like milk and bread. Then, to be sure of getting enough vitamins, we should be sure to drink some fresh

milk and to eat some fruits or uncooked vegetables, like lettuce. Fruit and vegetables, whether cooked or uncooked, also give us bulky material which helps our bowels to act. Milk is a very good food, especially for children; it helps them to grow.

Some people use very little food except bread and jam and cereals and potatoes; these are cheaper than meat and

FIG. 83.—*A varied diet: Water, milk, bread, butter, meat, vegetables, potatoes, salt, eggs, fruit, lettuce, jam, cheese.*

eggs and milk, but by themselves they give too much fuel food and not enough body-building food. Other people, especially in big towns, live almost entirely on tinned food. This is bad, because there quite possibly will not be enough of one or other of the vitamins in tinned foods, and also because many tinned foods, though tasty, are not very digestible.

EXERCISE AND SLEEP

Exercise and sleep are also very important. Exercise does several things for us. It burns up food-material in our muscles, so that it gives us a good appetite and helps

us to use up our food quickly. It sends the blood coursing through our veins, and makes the different parts of our bodies work more actively, as well as getting rid of waste material more thoroughly.

It makes our muscles grow bigger and stronger than they otherwise would. Muscles and bones only develop to their full size if they are used. If you took two twin boys and kept one sitting at a desk all day with the least possible exercise, while the other one was brought up to do farm work, you would find after a few years that the farm boy was bigger and heavier and stronger. Strength of muscle is not the most important thing in life, but all the same, to be strong makes a great deal of difference to one's happiness and one's health. You must avoid getting over-tired by trying things beyond your strength, and you must not give so much time and energy to exercise and games that there is not enough left over for all the rest of life. But you will be wise to take a little real exercise every day.

Some kinds of exercise are useful in another way. You have all seen a kitten playing with a dead leaf or with something you dangle in front of it on a string, pretending to stalk it and then making a rush and a pounce. The kitten enjoys the game, but also, without realising it, she is training herself in the use of her eyes and her muscles, so that when she grows up she will be better able to catch and kill mice and rats. So with

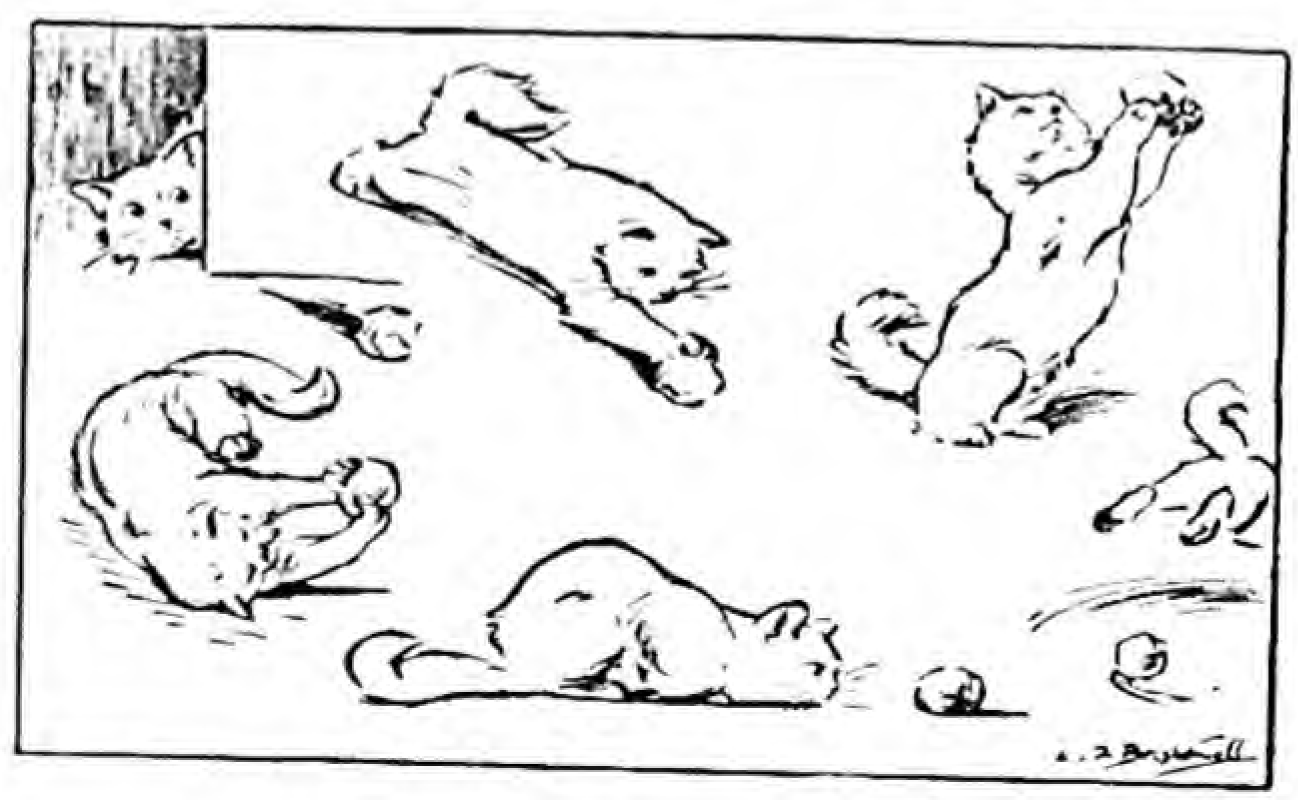


FIG. 84.—*Play: a kitten with a paper ball.*

our games; they train us in various ways. Some teach us how to control our muscles, others how to control our feelings. Some help us to use our hands and eyes together, others are good for quickness of mind or concentration or memory. Some people become so absorbed in games that they forget about real life; but, so long as you do not do this, games are not only fun, but can help you in real life.

Sleep is as important as food. You will not develop properly in body or mind if you do not have enough sleep, however much food you eat. When you are growing, and when you are learning new things all the time, you need a great deal of sleep; that is why children must have more sleep than grown-ups. Different people need different amounts of sleep, just as different people need different amounts of food. The sleep that you get soon after going to bed is deeper and more refreshing than sleep at the end of the night. So to lie in bed half dozing in the morning is a wasteful thing to do; you are not getting a great deal of rest out of it, but are only being lazy.

Regular habits are good for sleeping as well as for eating; your body gets used to doing things at a regular time and in a regular way, and does them without effort. However, too much sameness is a bad thing; you get bored or your habits grow so strong that you become set in your ways and unwilling to try anything new. So now and again, when there is something interesting happening, it does no harm to sit up late, just as now and again it does no harm to have a picnic or a feast and eat differently from usual.

Cleanliness and Health

Cleanliness is another help to health. Nobody expects children, or grown-ups for that matter, never to get their

hands or feet or clothes dirty; but this does not prevent cleanliness being a good thing. For one thing, dirt is unpleasant. There are still some parts of the world where many people go for a long time without washing, wear filthy, ragged clothes, do not care if their hands or their hair are dirty, have fleas and mice and flies and cockroaches all over their houses, and live in dirty surroundings without taking the trouble to get rid of rubbish and filth in a sanitary way. Anyone who has been among people who live like this will tell you how unpleasant and disgusting it is.

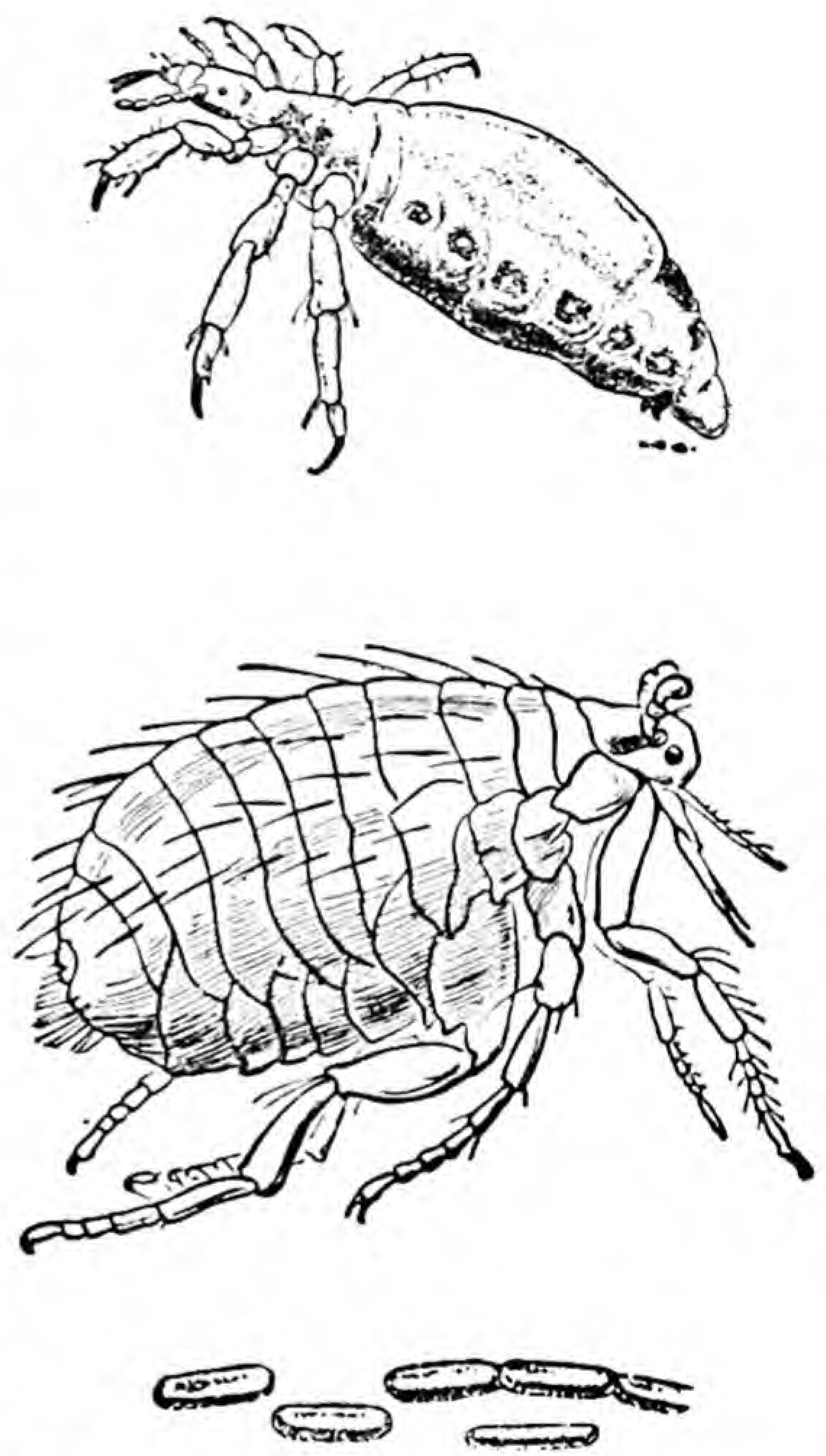


FIG. 85.—*Above, a louse, much magnified. Lice spread typhus fever. Centre, a rat-flea, much enlarged. Rat-fleas spread plague. If the flea bites a man after biting a rat which has plague, some of the plague bacteria from the rat's blood find their way into the blood of the man. Below, some plague bacteria, very highly magnified.*

But dirt is not only unpleasant; it is also dangerous. We have already explained (Part I, p. 28) how the "seeds" or *spores* of bacteria float about in the air. When they settle down they will be mixed up with dust and dirt, and if this is not cleared away the spores stay there ready for a chance to grow into bacteria and reproduce themselves. If

they are of dangerous kinds they may infect people and give them diseases. Then, too, disease bacteria are often found in dirty water and sewage. If any of this gets into drinking-water, the people who drink it may get serious diseases, such as typhoid fever.

Some animals carry disease-germs from one person to another. There is a terrible disease called bubonic plague, which is carried by the fleas which live on rats. The flea bites a diseased rat and gets some germs into its mouth; the germs live and multiply inside the flea. If the rat dies, the flea will leave the body; then if it happens to jump on to a man and bite him, the man will get the disease and probably die. The Great Plague of London in 1665 was this disease. The number of people in London then was less than half a million: in a few months about 70,000 of them died, and about 300,000 fled from the city. If the houses in London then had not been full of rats, the terrible disease could not have spread as it did.

After the war, in Eastern Europe and Russia, thousands of people died of a disease called typhus. This is carried from one person to another by lice, which are horrible little parasites that can only live on people who do not wash properly.

Even the common house-fly is dangerous if there is dirt about. Flies will crawl all over filth and sewage, and then come into the room and crawl over your food or dip their feet in your milk. They also have a nasty habit of pumping up what is in their stomachs on to their food, as shown in the picture; this dissolves some of the food, and then they suck the drop in again. It is only a little dirt which can be carried on a fly's foot or tongue, but it is enough to contain hundreds, or even thousands, of the most dangerous germs. So it is a good thing to have as

few flies around as possible, and if you cannot get rid of all the flies, it is important that there should be no filth or rubbish in which they can infect their feet or their tongues with germs.

Then again, soap and water not only gets rid of dirt, but it also helps to keep the skin healthy, and a healthy skin helps to keep the whole body healthy.

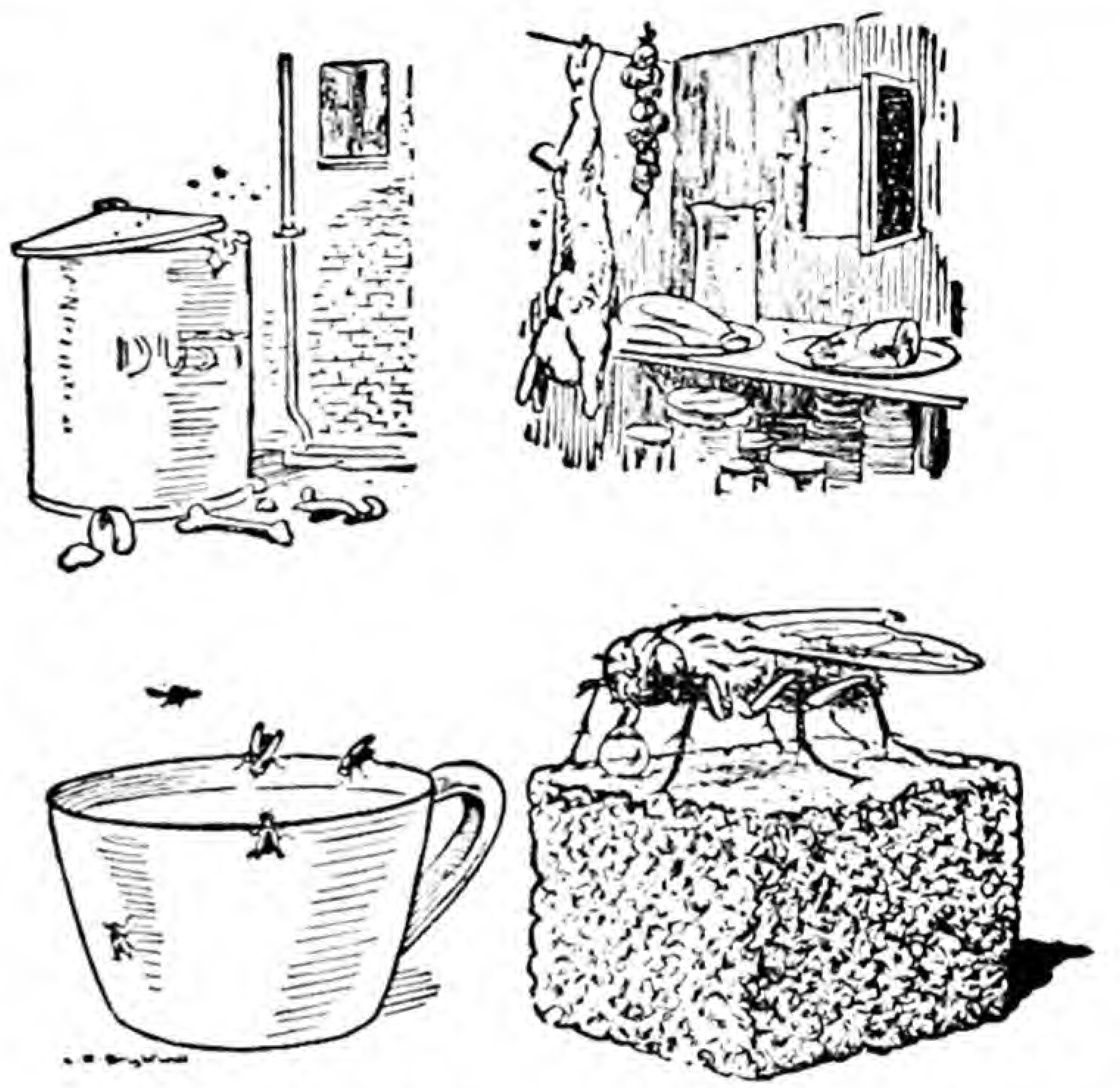


FIG. 86.—*How flies spread dirt and disease. The fly in the right-hand bottom corner has squirted out some liquid from its crop (the first part of its stomach) through its tongue on to a lump of sugar: the liquid dissolves some of the sugar, and then the fly will suck it up again.*

Your skin is a wonderful protection against dirt and disease-germs entering your system; but if you cut yourself they are able to get right inside you. That is why it is so important to wash out a wound, especially when dust or dirt has got into it, and put on some antiseptic (or germ-killing) liquid before bandaging it up.

There is one part of the body in which cleanliness is important in rather special ways, and that is the mouth. It is so easy to get decayed teeth, and these are bad for you in so many ways, that you should take special trouble about them. Some kinds of food, like apples, are good after

a meal for cleaning away from the teeth scraps of food like meat which are liable to decay. Cleaning the teeth, especially at night, is important, for otherwise bits of food in the cracks between the teeth go bad and holes develop in the teeth. Rubbing your gums, but not too hard, with a tooth-brush dipped in ordinary salt is good, because it makes the gums healthy and prevents infections from getting down to the roots of your teeth. Diet and general health, too, make a difference to your teeth. If for any reason there is not enough lime in your blood, your teeth will decay easily. It is also very important to have a dentist look at your teeth regularly. Sometimes there is a little infection down at the roots of several teeth. It is not enough to hurt you, and you do not bother about it, but all the while it is sending a little poison into your blood, and after a time it may make you feel quite sick, with headaches and tiredness. Also, of course, bad teeth prevent you chewing your food properly.

Finally, do not forget the inside of your body. It is just as dirty to let food-rubbish stay too long in your bowels as it is not to wash your face and hands. It is also just as important to keep the inside of your body clean as to keep the outside clean. Regular action of your bowels will prevent you from being made ill by the poisons in your food-rubbish, just as washing will keep you free from various germ-diseases.

Before the nineteenth century, life even in a great city like London or Paris was very dirty. Slops and filth were thrown into the gutters, refuse and rubbish were not regularly carted away, but piled up in back-yards or allowed to lie in the streets. The streets were not washed clean every day, and in wet weather were deep in mud. Rats and mice ran about even in fine houses, and parasites like fleas and

lice were common. The poor people hardly ever took a bath, and even the rich only did so now and again; they used a great deal of strong perfume to cover up the disagreeable smell of their unwashed bodies.

FIG. 87.—*Left, early morning in a London street in the seventeenth century. The gutter took up most of the middle of the road, and people emptied the slops out of their windows; rats were common. Right, early morning in a London street today. The street is cleaned by water from a hose pipe.*

As a result, people did not live nearly so long on the whole then as they do today, and many dangerous diseases which now are very rare were common then. People thought themselves lucky if some time in their lives they did not catch the smallpox, which, if it did not kill them, left their faces pitted all over with ugly pockmarks. They were always catching fevers like scarlet fever and typhoid fever, and typhus was so common in the prisons that it was called jail fever. We ought to be thankful that we live in

a time when people have learnt how to keep themselves and their houses and their cities clean.

There are many other interesting and important things about health and disease, but we have no room to talk about them here. Simple, varied food; sensible clothes; plenty of fresh air; cleanliness; enough sleep; regular exercise—these are the chief things which help you to keep your bodies healthy.

However, you have not only got a body, but also a mind, and it is just as important to have a healthy mind as it is to have a healthy body. Not only do you need a healthy, active mind to get on in life, but an unhealthy mind will have an effect upon your body and make it unhealthy too.

You need to exercise your mind if it is to develop, just as much as you need to exercise your body. You do not go to school just to learn particular things, though this is important; you go there also to train your mind to work quickly and strongly.

Two things above all are necessary if you are to keep your mind healthy. One is to be interested in things; the other is not to worry. Without an interest outside your own little affairs, you will find you get bored and sluggish. The world is so full of interesting things and people that it should not be difficult to find many interests for yourself; they will help to keep you alert and keen and make life more worth living.

Worry is simply a bad habit. It means fussing about yourself and the accidents and bits of bad luck which may happen to you, and it means fussing about them in a stupid and useless way. Some people worry so badly that they become quite ill, and get headaches and cannot sleep properly; and then, of course, their bodies suffer and get less healthy. Other people, with just the same troubles,

manage not to worry too much over them, but make up their minds to go ahead and see what they can do, and to look as much as possible on the bright side of things; people like these will keep their bodies healthier as well as having happier minds. Which sort of person do you think it best to be?

Not worrying about things is not the same as not thinking about them. It is as stupid not to think as it is senseless to worry uselessly. Perhaps the most important rule of all for health is never to fuss or worry about things, but to face them and think sensibly about them as they turn up.

CHAPTER VI

HOW PLANTS LIVE

Plants are Built Differently from Animals—How Water Travels through Plants—The Food of Plants—Plants and Oxygen—The Difference between Plants and Animals—Flowers and Seeds—Insects and Flowers—Seeds and How They are Distributed—The Usefulness of Plants

Plants are Built Differently from Animals

EVERYONE knows that ordinary plants, like beans or lilies, are very different from ordinary animals, like cats or fishes. The animals can move about; the plants are fixed in one place. The plants are green; the animals are not. The animals have all sorts of things which the plants have not got, such as eyes and ears, heart and stomach, limbs and brain; and the plants, on the other hand, have many things which you do not find in the animals, such as leaves, roots and flowers.

The general construction of an ordinary animal we have described. It has a head, a main body or trunk, and limbs. The head is in front, and has on it the mouth and the most important sense-organs, like the eye; inside it there is the brain. The animal has a stomach and digestive system, a heart and blood-system, a brain and nervous system. It has muscles and a skeleton, it has breathing organs and kidneys and sense-organs.

A plant, on the other hand, has a totally different construction. It has nothing that you can call head, body or limbs. It has a main stem, which goes down underground and turns into a root. Below ground the

root branches into smaller roots and eventually into hundreds of tiny rootlets. Above ground the stem may branch too, but its branches carry the green leaves. At some times of the year flowers grow on the stem or its branches, and from the flowers are developed the fruits and seeds.

FIG. 88.—*Plants live partly in the air, partly in the soil. A buttercup plant showing stem, leaves and flowers above ground, roots below ground.*

Why is there this difference? Many people do not trouble even to ask themselves the question, but it must mean something. We can be sure, too, that it is important to the plants. Their flowers do not exist just to please us by looking so beautiful and smelling so sweet, and anyhow, there are plenty of plants with plain or ugly flowers, or flowers with an unpleasant smell. Animals eat the green leaves of plants, but the leaves are not there merely to be eaten by the animals.

When we talked of the animal body we discovered that every part had some special work to do, and that its whole construction had a meaning in connection with the life of the animal. Just the same thing, we shall find, is true of plants: every part of the plant—root, leaf, stem, flower, fruit and seed—has its special work to do. Its construction has a meaning in relation to its life.

But the construction of a plant is totally different from the construction of an animal. This difference in construction must mean an equally big difference in their life.

This is the first thing, then, that we want to find out. What is the great difference between a plant's way of life

and an animal's way of life? Once we have discovered this, many other facts about plants will be easy to understand. Many simple experiments can readily be carried out on plants, and the best thing to do will be to describe a number of experiments which will enable you to find out for yourselves how plants live.

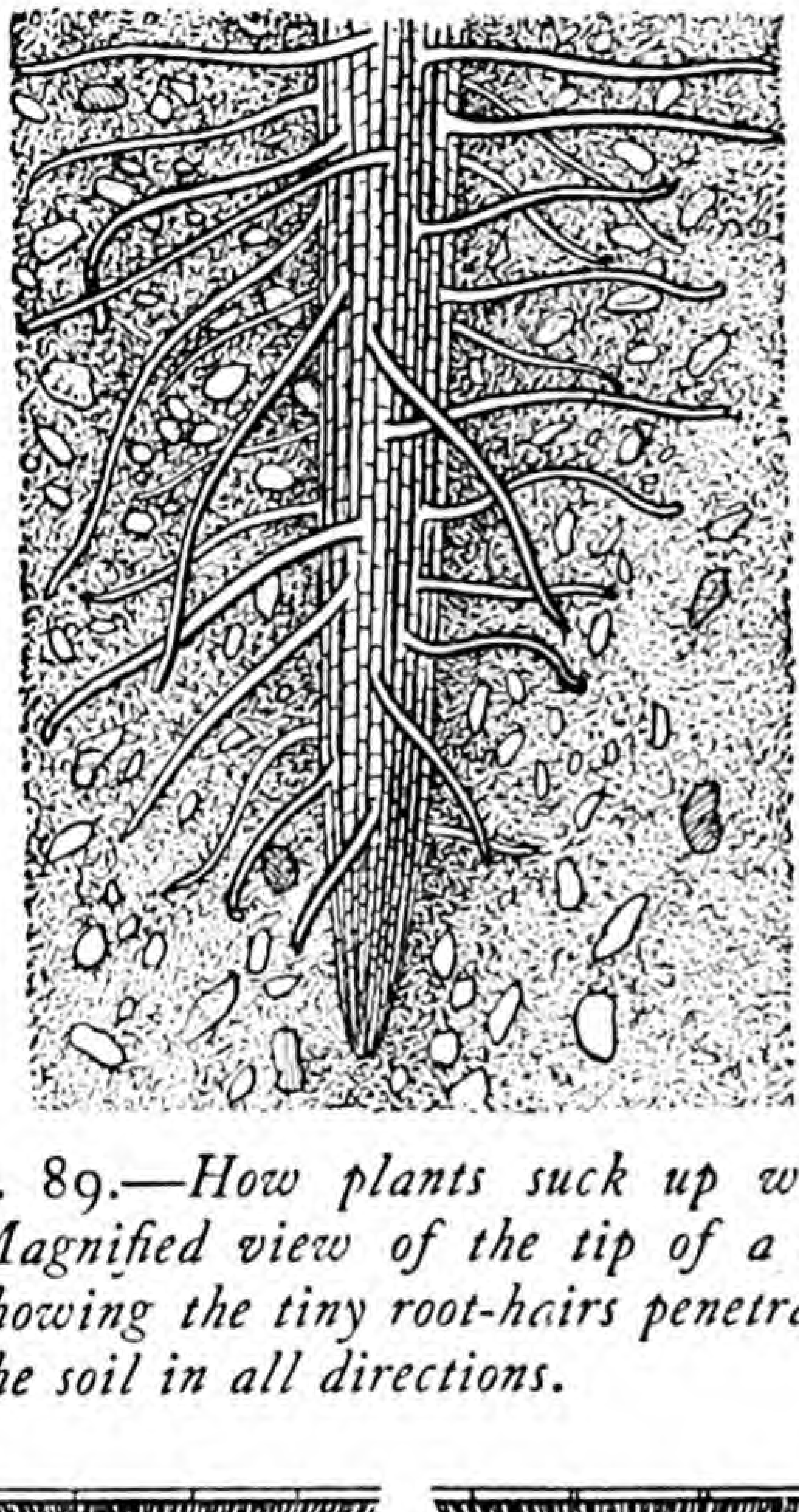


FIG. 89.—*How plants suck up water. Magnified view of the tip of a root, showing the tiny root-hairs penetrating the soil in all directions.*

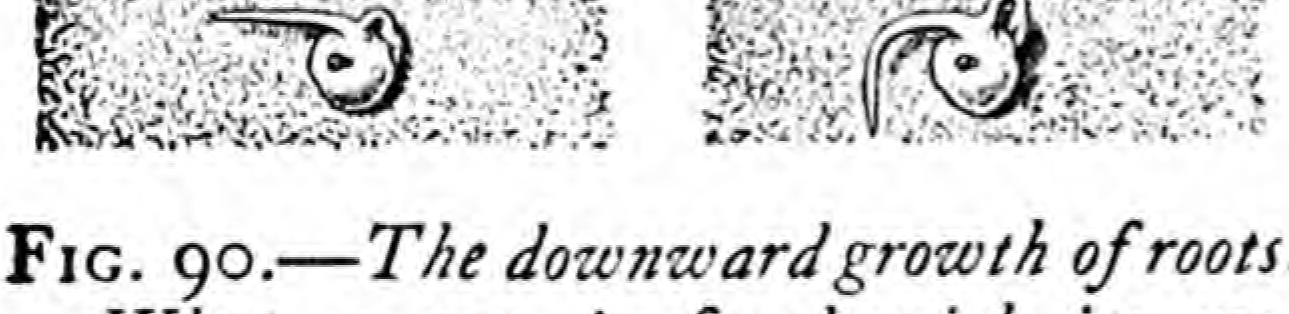


FIG. 90.—*The downward growth of roots. When a pea is fixed with its root horizontal, the root bends over until it can grow straight downwards.*

Let us begin with the water that plants need. Everybody knows that plants have to be watered in dry weather. You can carry out a very simple experiment to see what a lot of water they use. Take two tumblers, and fill both of them to about the same level with water. Over one of the tumblers arrange a plant—any small plant will do—so that its roots are in the water; you can do this with a framework of wire bent over the edge of the tumbler. Then pour a thin film of oil on top of the water; this is to stop the water from evaporating. If you mark the level of the water in both glasses every day by means of thin strips of stamp-paper,

you will see that the level in the tumbler with no plant in it does not change, while that in the other drops a little every day. This can only mean that the plant is taking water from under the oil film by means of its roots. If you look at the tip of a rootlet with a magnifying glass, you will see it is covered with a fuzz of tiny hairs. It is these *root-hairs* which suck water into the plant.

When a plant is growing naturally, in order that the roots should be able to suck up water, they must penetrate downwards into the soil, and they must go where the soil is damp. Roots are made in a wonderful way so that they grow directly downwards. To show this, take some peas or beans that have been soaked, plant them in moist sawdust, and wait until their roots have grown to about an inch long. Then take a small box, line it inside with wet blotting-paper, and pin a few of the peas or beans to one side in such a position that their roots are horizontal. Put on the lid and leave the box. By next day you will find that all the roots have bent round so that their tips are now pointing downwards.

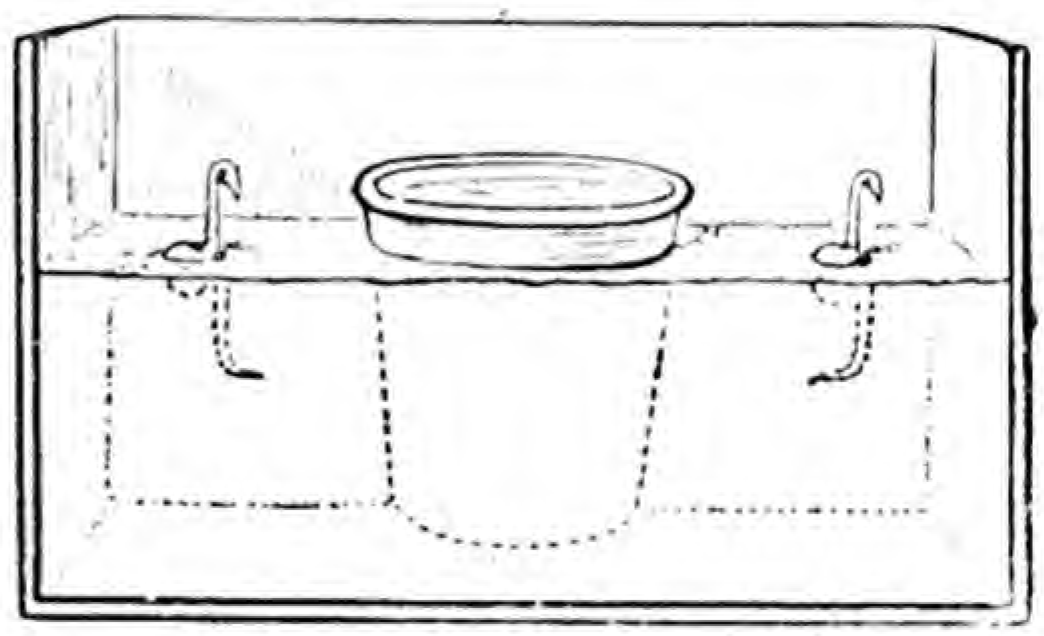


FIG. 91.—*Roots grow towards moisture. Bean seedlings are planted in dry soil with a flower-pot full of water in it. Their roots bend and grow towards the water that leaks out of the pot.*

To show that the roots grow towards moisture, you can do another simple experiment with peas. Fill a wooden box with nearly dry soil. In the middle put an ordinary unglazed red flower-pot with the hole at the bottom corked up, so that only its rim shows above the soil. Plant some previously soaked peas near the edges of the box, and fill

the pot with water without watering the soil in the box. It is rather important to take a new clean pot, for then the water is sure to be able to leak through its sides into the soil. After two or three weeks, during which time you have kept the pot filled up with water, carefully dig round the seedling peas with a knife until you can see their roots. You will find that in each case the root and all its branches are always bent round so as to be growing towards the moisture which is coming from the pot.

An even more striking experiment is as follows. Take a fine-meshed sieve, put some wet filter-paper inside it over the meshes, some mustard and cress seeds on the filter-paper, and a good layer of wet sawdust over the seeds. Then hang the sieve up in a slanting position as in the picture, if possible somewhere where the air is moist. The seeds will begin to grow, and their roots will sprout down through the filter-paper and the meshes of the sieve. After a little, however, they will be attracted by the moisture in the filter-paper and sawdust, and will bend round so as to grow towards the sieve again. In these cases, the tendency to grow towards moisture has proved stronger than the tendency to grow straight downwards.

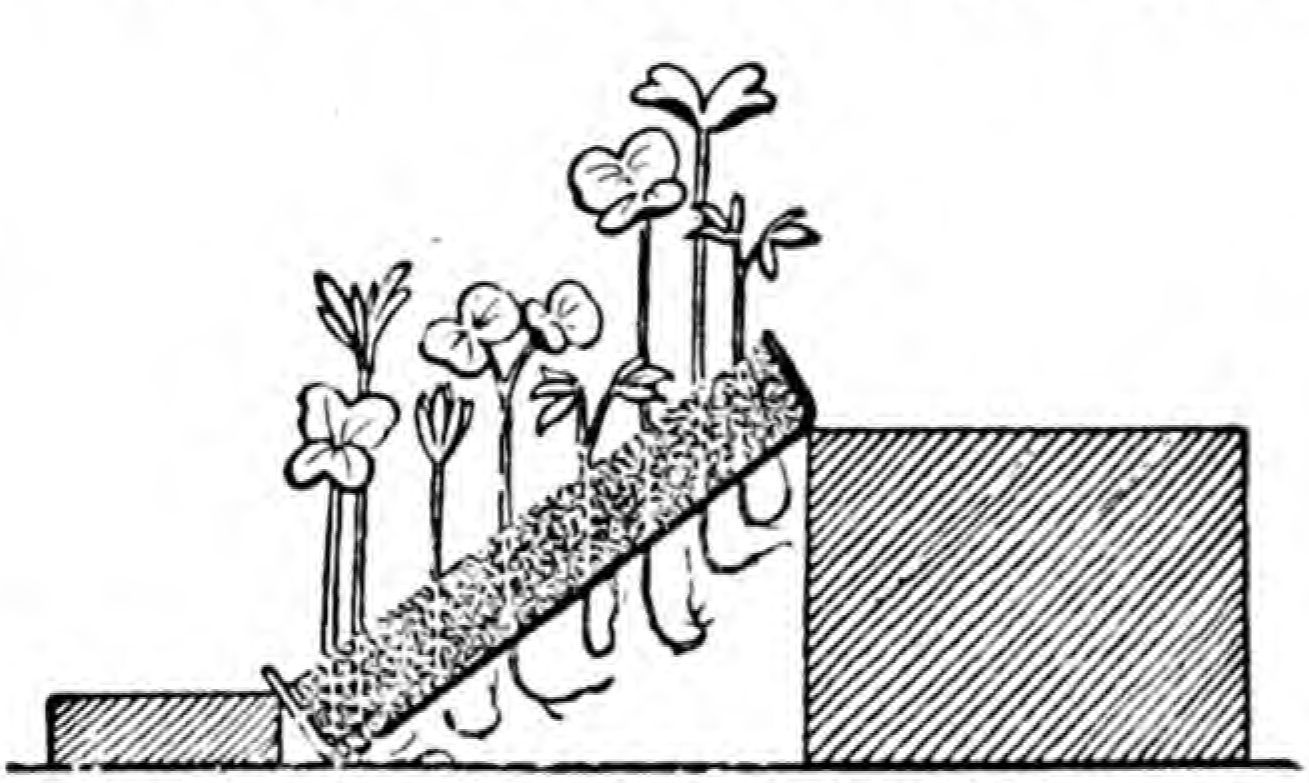


FIG. 92.—*Roots grow towards moisture. When mustard and cress seeds are sown on a slanted sieve filled with wet soil, their roots grow down through the sieve and then bend round towards the moisture in the soil.*

How Water Travels through Plants

What happens to the water which the roots take up? Here is another experiment to help us to find an answer to this question. Take two pots with earth in them, and plant some plants in one but not in the other. When the plants are growing well, water both pots thoroughly, and then, after letting any extra water drain away, cover both pots and the surface of the earth in them with "silver paper" (which is really tin beaten out very thin). This is to prevent the water from evaporating through the surface of the earth or the sides of the pot. Now weigh the two pots carefully, and go on weighing them every day for a few days. You will find that they both get lighter; but while the one with no plants in it only gets a very little lighter, the other loses a good deal more weight. If after some time you look at the soil in the two pots, you will find that it is drier in the pot with the plants. This must mean that the plant is sucking up water from the soil with its roots, and getting rid of it, or of some of it at least, into the air in the form of invisible water vapour.

The water travels up from the root through the stem to the leaves. You can see this by putting a plant into a coloured liquid, like red ink mixed with a good deal of water; (for the experiment to succeed well you must cut the tips off the roots first). After a few days, if you pick a leaf and hold it up to the light, you will see that the midrib and veins of the leaf are red. The water does not simply soak up, but travels along certain definite channels. This you can see by cutting the stem across. Most of it is colourless, but some patches are red: these are where the water and ink are travelling upwards.

Water does not only travel to the leaves. If you take

some white flowers like white jonquils or narcissus, and put the cut ends of their stems into the weak solution of red ink, by next day streaks of red will appear on the petals. The water travels to every part of the plant. Later on, we shall tell more about the channels along which it travels.

You can also find out where it escapes from the plant. There is a substance called cobalt chloride which is bright blue when it is dry, but pink when it is wet. If you dip a piece of white blotting-paper in a solution of cobalt chloride, which is pink, and then dry it in front of a fire, it will turn blue, but if you then breathe on it, the moisture in your breath will turn it pink again. You can use this as a test for where the water vapour is leaving the plant. Put a little bit of the blue blotting-paper (be sure to have it very dry) on either side of a leaf of almost any common plant, and then put a thin piece of glass on either side to keep away moisture from the air. In quite a short time you will see that the blue colour is fading and turning into pink, but this change of colour goes on quicker in the piece of paper which is against the lower side of the leaf. When the same sort of experiment is done with other parts of the plant, such as stems or flowers, the cobalt chloride will show very little change of colour.

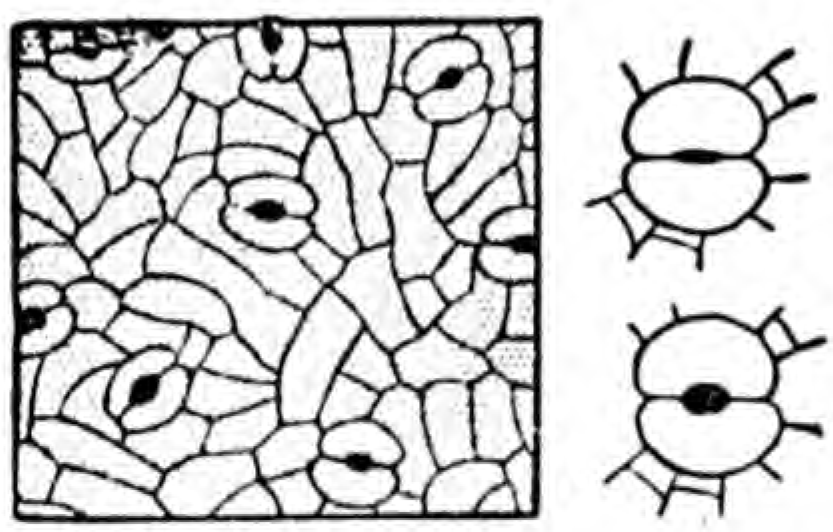


FIG. 93.—*How plants breathe. A magnified view of the under surface of a green leaf, showing the microscopic pores which lead into the interior. Right, below, a pore wide open in wet weather; above, a pore nearly shut in dry weather.*

The last experiment can only mean that the plant gets rid of its water vapour through its leaves, and especially through their under sides. If you look at a leaf under a

microscope, you will understand why this is so, and how it happens. On the surface of the leaf are hundreds of tiny holes called *stomata* (which is Greek for mouths), and in most plants there are many more of them on the lower side of the leaf than on its upper side. These little holes lead out of microscopic air-spaces inside the leaf. It is through them that the water vapour escapes.

You can try another very simple experiment to show that water escapes through the stomata on a leaf. Take two leaves which have stomata only on their under surface (lilac leaves are an example), and vaseline the upper surface of one and the under surface of the other. The film of vaseline makes it very difficult for water to evaporate. You will find that the one with the upper surface vaselined dries and shrivels up quickly, while the other stays moist much longer.

If there is not enough water coming up from the roots to make up for what is being sent out into the air through the holes in the leaves, the plant wilts, as gardeners call it. It begins to shrivel and collapse, and will soon die. Though a plant which is beginning to wilt can be revived by watering it, after a time things will have gone too far, and no amount of water will keep it from dying.

Plants are made so that some water must always be passing out through their leaves: but clearly it would be useful if, when there was a danger of losing too much water, it could be arranged for them to lose less than usual. This is done partly by altering the shape of their stomata. Each of the tiny holes lies between two sausage-shaped units of the leaf's surface. These are made in such a way that when the air is wet they bulge out and get more curved, somewhat as the inner tube of a bicycle tyre rounds out into a circle when you pump it up. This will make the

hole bigger. When the air is dry, on the other hand, they shrink and straighten so as to make the hole narrower, as shown in the picture (Fig. 93). Of course, when the holes are nearly shut like this, much less water vapour can escape, and so the plant is prevented from wilting so soon. Each hole is very tiny, but there are a great many of them, so that the plant can get rid of a great deal of water. A single sunflower leaf may have more than ten million stomata.

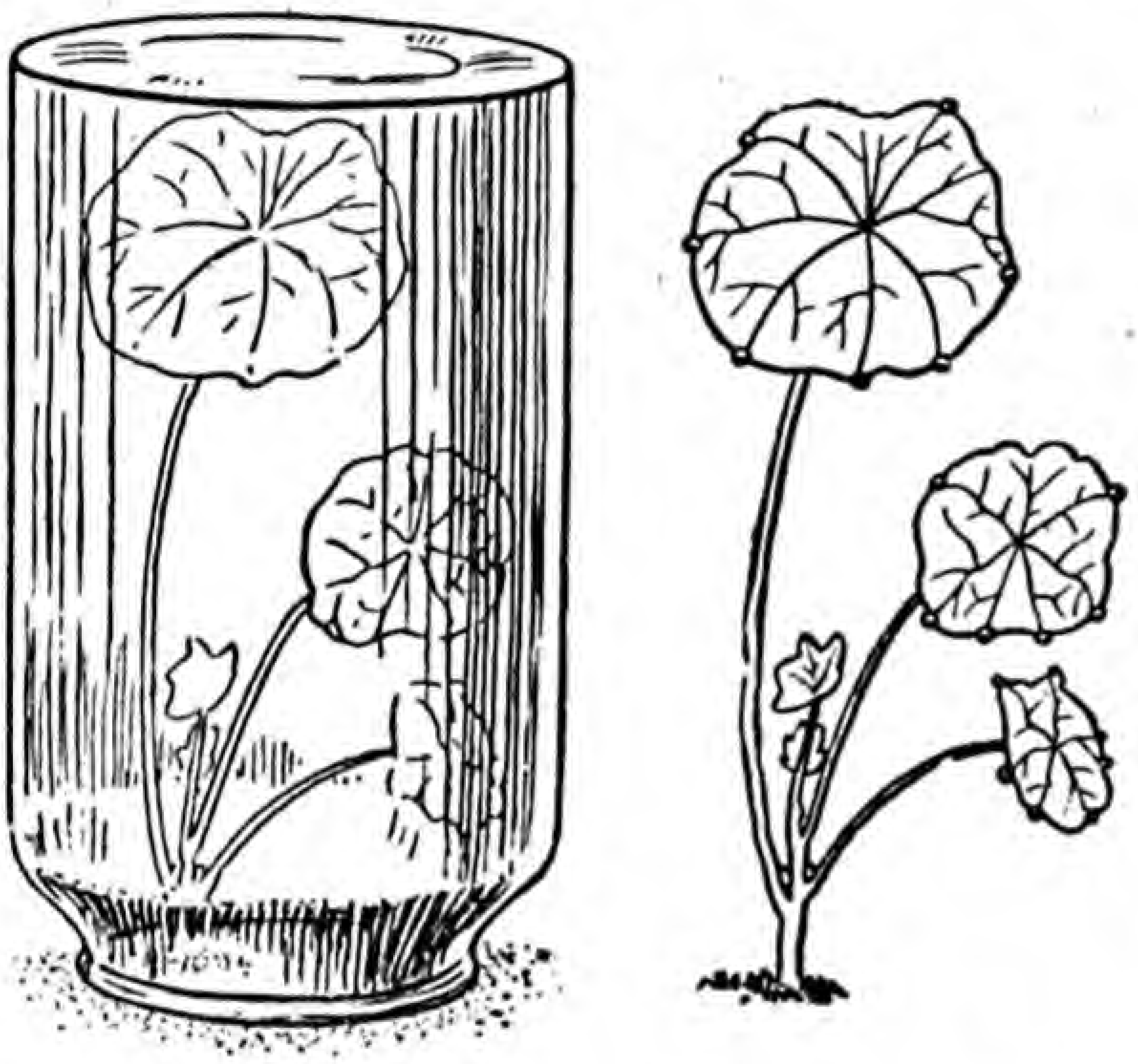


FIG. 94.—*Root-pressure. If you water a nasturtium plant on a summer night and cover it with a jar, next morning you will find that the root-pressure has forced drops of water out at the tips of the leaf-veins.*

It is still rather a mystery how the water gets up from the roots to the rest of the plant. In spring the roots help to pump it up. This you can show by taking a potted plant (a fuchsia will do very well) and cutting off its stem a couple of inches above the soil. Then slip a glass tube of just the right size over the cut end of the stem, and fix it by means of a connection of rubber tubing, which you make air-tight by tying it with wire. Tie the glass tube to a stick in the pot, or fix it to a clamp outside, and stand the pot in a saucer of water. You will find that water appears in the tube, and rises gradually day by day. The roots are pumping water up. It is owing to this "root-pressure" that, if you cut across the stem of many kinds of trees in the spring, you will see drops of water ooze out of the cut surface; as gardeners say, "the sap is rising."

Later in the year, however, this will not happen. By then a great deal of water vapour is escaping from the leaves, and this seems to cause water to be sucked up the stem from the roots, though we do not quite understand how this happens.

In summer, if the water vapour cannot escape easily, as will be the case when the air is very moist, and if the activity of the roots is increased, as will happen on a warm night, root-pressure will come into play. After a warm, moist night you may see plants with little drops of water actually forced out of their leaves by root-pressure. These are often mistaken for dew, but they are not dew. For one thing, you would not get dew after a warm night. For another, the drops are always at particular places—namely, at the ends of the leaf-veins, which are simply bundles of little pipes to conduct water and other substances from place to place inside the plant: the central vein of a leaf is often called its midrib. On grass or corn plants, the drops are squeezed out at the tips of the leaves; in nasturtiums, at intervals round the edge.

If on a warm summer evening you thoroughly water the soil round a nasturtium plant and then cover the plant with a bell-jar, in the morning you will see the little drops on its leaves. It is interesting to try the experiment with various plants: Lady's Mantle, for instance, is another good one.

The Food of Plants

In your experiment to show root-pressure with the fuchsia plant, you will find that after a week or ten days the water will stop rising in the tube; the roots are dead, and can no longer go on pumping. If you had not cut the stem off, the roots would have gone on living. So we may

guess that the roots gradually died because of the lack of something in the nature of food which they usually get from the stem or the leaves. We must try to find out if this guess is true.

FIG. 95.—*The effect of darkness in plant growth. Left, bean seedlings grown in the dark for a week: the rule on the right marks inches. Right, a bean seedling grown for the same length of time in the light.*

Most people know that green plants cannot live in the dark. If you grow plants in a dark cellar they will lose their green colour and eventually die. Seedlings or sprouting bits of potatoes grown in the dark will manage to live and grow for some time on their reserve stores of food, but they will have small leaves and will be thin and lanky and quite white in colour. The long white stalks of celery leaves that we eat are obtained by heaping up earth round them to deprive them of light: if they were grown in the light they would be green and short and not so tender. After a time, the seedlings in the dark will stop growing and die. If, however, you take them out into the light before they have stopped growing they will soon turn green, and then will go on growing quite healthily. This shows us two things—that green plants only become green in light, and that light is necessary for them to make their food.

The next step is to see if we can discover what food-substances plants make in the light which they cannot make in the dark. As a matter of fact, it is easy to find out that

starch, which we spoke about in the last chapter, is a substance of this sort. As we saw in the last chapter, carbohydrates are the chief source of fuel for the slow combustion that goes on in our bodies. They are also the fuel material for plants. If we eat starchy foods, the starch is turned into sugar and used for fuel by our muscles. In plants sugar, too, is used for fuel: whenever there is any extra amount of carbohydrate available, it is stored up in the form of starch, which, since it does not dissolve, will not leak away.

It happens that it is very easy to find out whether starch is present in a plant or not, because it turns deep brownish-blue with iodine: you can easily test this by adding a drop of tincture of iodine to a solution of a little ordinary grocer's starch. Next take some leaves from a plant that has been for some days in the dark, and some more leaves from a plant growing in the light (it is best not to have too intense light). You cannot test the leaves for starch by just dipping them in the tincture of iodine, because their green colour prevents you seeing the brownish-blue of the starch: you must first get rid of the green colour. This you can do by putting the two sets of leaves into boiling water (it is best to put them in separate vessels), and then letting them soak for some days in methylated spirit. The spirit dissolves out the green colour, and the leaves will become quite colourless.

Now paint a leaf from each of the two lots with tincture of iodine. You will find that there is no change in the leaf from the plant that has been in the dark, while there is a deep stain on the leaf that has been in the light. If you put the plant that has been in the dark back again in the light, and test one of its leaves after a few days, you will find that now there is starch in it. So starch is produced

in the light, and used up in the dark. The plant needs the energy of light to help it to make starch.

You can do another experiment to prove this. Clip or pin the leaf of a growing plant between sheets of black or silver paper, and cut a hole in the paper over the upper side of the leaf. After a day or so pick the leaf (it is best to pick it in the late afternoon after a sunny day), and then

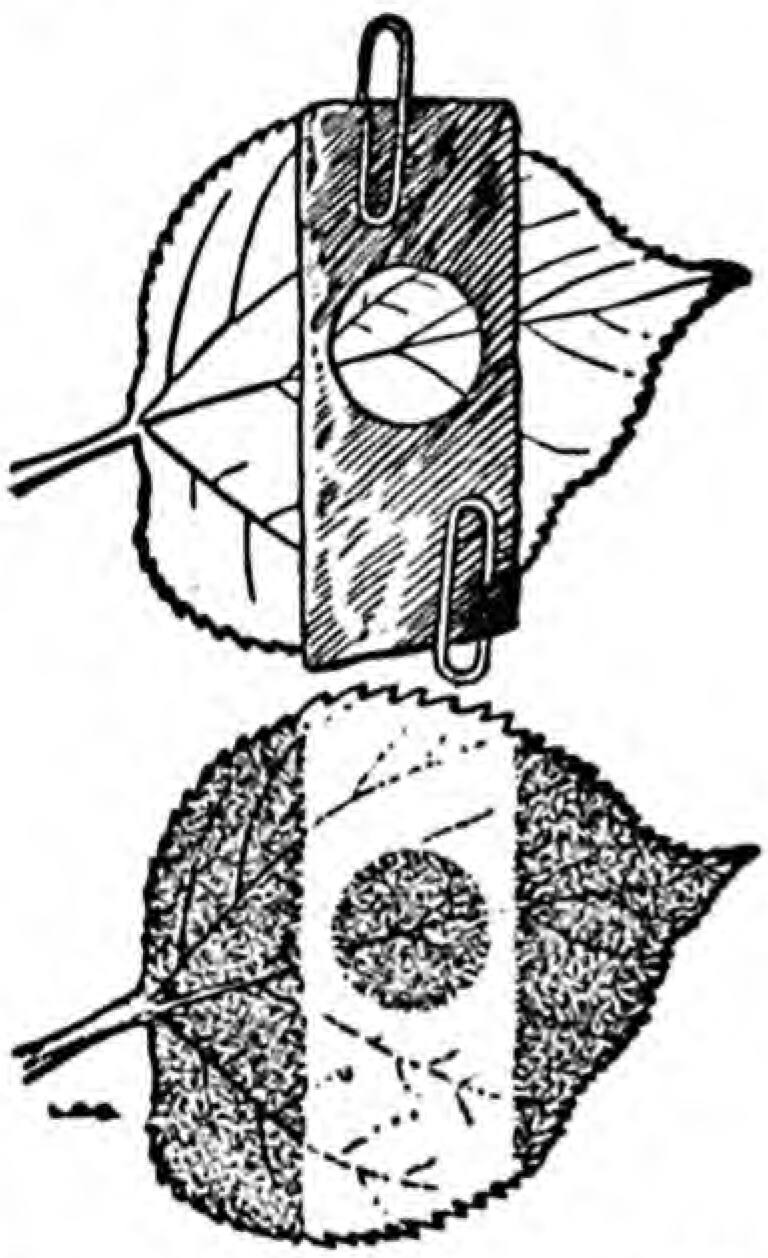


FIG. 96.—*Above, making a starch-print on a leaf. Below, the starch-print after you have treated the leaf with boiling water, methylated spirit, and iodine.*

FIG. 97.—*Variegated leaves. Left, Euonymus: green centre and yellow border. Right, Laurel: green with pale yellow patches.*

test for starch as before. You will find that the bluey colour is only found where the leaf was not covered by the paper: you have made a "starch-print" of the hole. By using stencils, you can "starch-print" letters or words on a leaf if you want to.

Another interesting thing to do is to take a leaf which is particoloured, or *variegated*, as it is usually called.

Leaves of this sort are only green in patches; the rest of them is yellow or white. There is a sort of privet with variegated leaves which will do quite well. Test some leaves of this sort for starch in the way described. You will find that there is starch in the green parts, but none in the yellow parts. Before testing, make a drawing of the leaf to show which parts are green and which are not. We have already shown that light is needed for the plant to make starch: this experiment proves that the substance which gives them their green colour is also necessary.

Fig. 98.—*Plants need carbon dioxide to make starch. The fuchsia plant in the jar can get no carbon dioxide; all the carbon dioxide in the jar is taken up by the dish of caustic soda solution, and the soda-lime in the* U-*tube prevents any more getting in from outside. After a few days, there will be no starch in the plant's leaves.*

The next thing is to discover from what raw material the plant makes its starch. It can get the hydrogen and oxygen from the water taken in by its roots, but where does it get the carbon? This is not quite so easy to find out, but an experiment can be arranged to show that the carbon dioxide in the air is the plant's source of raw carbon.

Take a jar large enough to hold a potted plant, and put a dish of caustic soda solution in it together with the plant. Then put a tube through a hole in the cork and to the end fix a U-tube with soda-lime in it. The whole apparatus must then be stood in the light.

Both the caustic soda and soda-lime take up carbon

dioxide from the air, so all the carbon dioxide in the jar is taken out of the air by the caustic soda, and the soda-lime prevents any more getting in, though the other gases in the air are able to enter. After three or four days, if you test the leaves of the plant, you will find no trace of starch in them; the starch they had before has been used up, and no new starch has been made.

As a "control" experiment, you should put another plant in an exactly similar apparatus, only with water instead of caustic soda solution, and powdered pumice instead of soda-lime. This plant will find carbon dioxide in the air in the jar, and when its leaves are tested, there will be starch in them. There is only a very little carbon dioxide in the air—usually about 3 parts in every 10,000 of air: yet the plant obtains all its carbon from this.

Fig. 99.—*An experiment to show that plants need oxygen. If the jar is kept in the dark, after a time the candle will go out.*

Plants and Oxygen

Carbon dioxide consists of carbon joined with oxygen. When the plant, by means of the green stuff in its leaves and the aid of energy from sunlight, splits up the carbon dioxide to get the carbon for itself, what becomes of the oxygen? The answer is easy—it gives it off again into the air in the form of oxygen gas. A simple experiment which illustrates this is to arrange a number of living plants in a saucer of water round the stump of a candle. Light the candle, cover the candle and the plants with a jam-jar placed mouth downwards, so that no more air can

get in, and put the whole thing in the dark. After some time the candle will go out, because it has used up all the oxygen in the jar. Then put the jar in bright sunlight. After two or three hours, if you quickly lift the edge of the jar and slip a lighted taper into it, you will find that it does not go out. This can only mean that in the sunlight the plants have produced a new supply of oxygen.

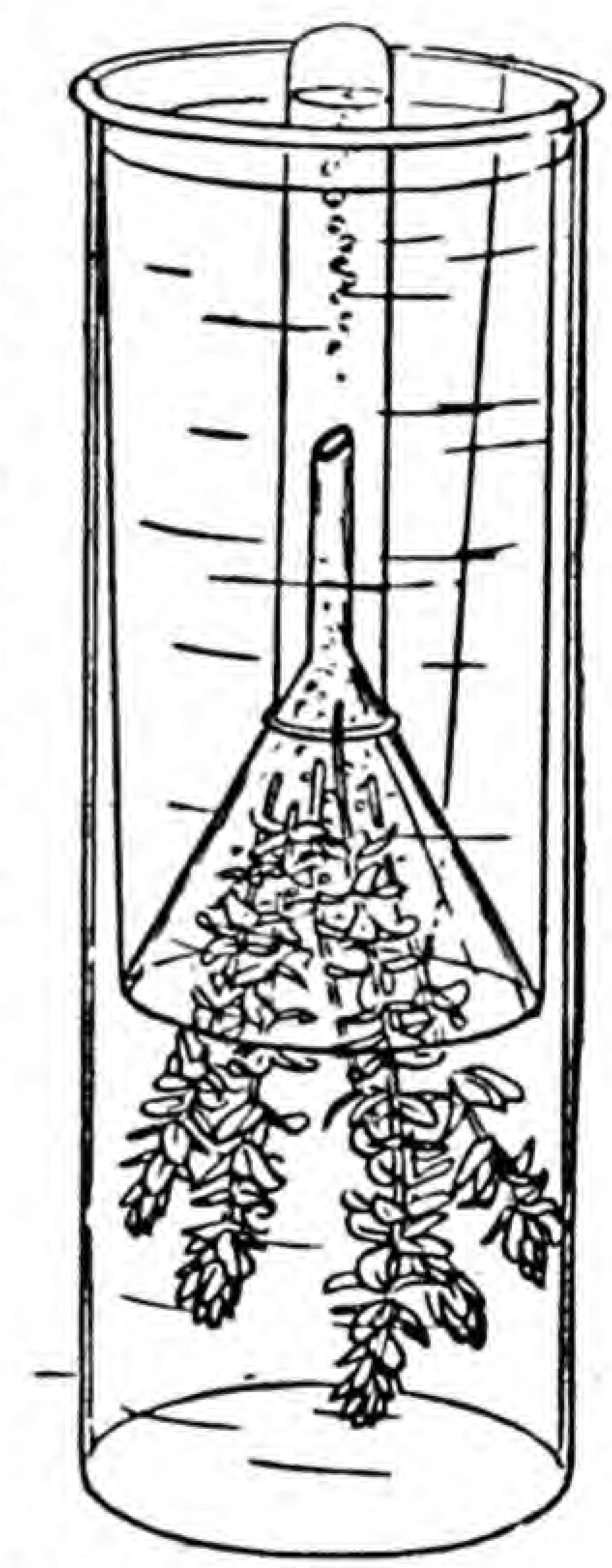


FIG. 100. — *Green plants give off oxygen in sunlight: collecting oxygen from Canadian water-weed.*

However, you can best show the giving off of oxygen by using a water plant: the common Canadian water-weed is the best to use. Put some bits of water-weed under a large-sized glass funnel in a vessel of water, fit a test-tube full of water over the stem of the funnel, and then place the whole apparatus in the sunlight. Almost at once bubbles of gas will begin to come off from the plant, and will bubble up into the test-tube. When the tube is full of gas (which will be after one or two days), take it off, and quickly push a glowing match or splinter into it. You will see the glowing end burst into flame, which proves that the gas in the tube is oxygen.

You can vary this experiment in interesting ways. If you put the jar with the water-weed in the dark, you will find that no oxygen is produced: light is necessary for the green plant to split off oxygen gas from carbon dioxide. If the vessel is in the light, and you add warm water, the bubbles of oxygen quite soon begin to come off more quickly; while if you add some powdered ice, they will

come off more slowly. So temperature influences the rate at which plants split up carbon dioxide, just as it influences the rate at which cold-blooded animals move (Chapter IV).

Then, if you use water which has been allowed to cool after being boiled so as to drive out all the gases contained in it, you will find that no oxygen at all is formed. This is because there is no carbon dioxide left in the water. (You can make quite sure of this experiment by putting the whole apparatus under a big bell-jar together with a small vessel with a solution of caustic soda in it. Any carbonic acid in the air is greedily taken up by the caustic soda, and so none can get into the water.)

If you now take the same vessel and mix some soda-water with the water in it, bubbles of oxygen will at once begin to be given off; and if you add plenty of soda-water, oxygen will be given off quicker than in ordinary unboiled water. You will get the same result if you blow through a tube into the water for some time. This is because, as we saw earlier, both soda-water and our breath have a good deal more carbonic acid in them than ordinary air does.

Thus, with the help of sunlight, plants can make carbohydrates out of water and carbon dioxide. If they need the carbohydrate at once, it is sent through the plant in the form of sugar dissolved in the sap. Otherwise it is turned into starch and kept in reserve.

But starch and sugar are not the only substances that are made in the leaves. The water that is taken in by the roots is not pure water, but contains various chemical substances dissolved in it. These are carried up to the leaves in the current of water that passes up the plant. We know that substances dissolved in water cannot escape

into the air in vapour form. It is easy to prove this by dissolving some sugar or some salt in a saucer of water and letting it stand. The water evaporates, but the salt or the sugar is left behind as a white crust. So when the water in the leaves escapes into the air through the stomata the dissolved substances stay behind; and they are used by the plant to build up the rest of the food-materials it needs. You can show by a simple experiment that the plant must get something besides water from the soil if it is to grow. First bake some soil in an oven, to kill any living things in it. Then take two big jam-jars. Next fill one with pure water — either distilled water or rain-water—and fill the other with distilled water in which the baked soil has been stirred up. Then rig up cardboard lids for the jars, and fix some seedlings—maize seedlings are convenient—in a hole in the middle of each lid so that their roots dip into the water. The soil all settles to the bottom, so that the roots of the plants in this jar do not touch any soil.

FIG. 101.—*Soil contains something which plants need for growth. Maize seedlings in pure water (right) hardly grow at all, while in water with soil in it (left) they grow well.*

You will find that the seedlings in the jar with soil and water will grow nicely, while those in the other jar will grow much more slowly, and after some weeks will die. This proves that the roots take up other substances besides water from the soil. These substances are of the chemically simple sort called salts, of which ordinary table salt is an

example. In a later Book we shall find out exactly what they consist of.

We spoke of the way in which green plants give off oxygen gas when they are taking the carbon out of carbon dioxide to make sugar and starch. This is just the opposite of what happens in animals, which use up oxygen in their breathing. As a matter of fact, however, plants do breathe, and they breathe in just the same way as animals, by breathing in oxygen and breathing out carbon dioxide. But when they are in the light, the opposite process of giving out oxygen goes on much faster, so that to study the breathing of plants you must keep them in the dark.

Take three jars which can be tightly corked up. In two of them put some living plants, and in the other the same number of dead plants. Cork up the jars, put the one with the dead plants and one of the others in the dark, and the third in the light. After about two days, test the air in each jar by quickly pushing a lighted taper into it. The taper will go on burning all right in the jar that has been in the light and in the jar with the dead plants, but it will go out in the jar that has been in the dark and has had live plants in it. The living plants in this jar have used up oxygen from the air, and as they were in the dark they were not making more oxygen out of carbon dioxide. The live plants in the dark have been breathing out carbon dioxide, as you can show by putting in a rod which has been dipped in lime-water; the lime-water will go milky, while in the jar which has been in the light the lime-water will stay clear.

By a slightly different experiment you can show that oxygen is absolutely necessary for the life of plants. Have two jars, as in the last experiment, each with a healthy growing plant in it. In one of them put a small beaker

with pyrogallic acid. Pyrogallic acid has the power of taking oxygen out of the air into itself. So although the plant in this jar is making oxygen out of carbonic acid, the oxygen is taken away by the pyrogallic acid as fast as it is made. The plant, as it can get no oxygen, suffocates, and after a few days you will find that this plant dies, while the other one, although tightly corked up, is quite healthy.

These experiments show that plants must breathe oxygen if they are to live; but what do they need the oxygen for? The answer is that plants, like animals, need

FIG. 102.—*"Sleep" movements in plants. The goatsbeard (left) closes its flowers at night and when it is cloudy and wet. The wood-sorrel (centre) folds its leaves at night. The scarlet pimpernel (right) closes its flowers and hangs them down at night and in wet weather.*

oxygen to produce energy through slow combustion. A plant does not need so much energy as an animal, as it does not move about from place to place. But so long as it is alive it needs oxygen, and the energy it gets from using oxygen in combustion for the processes of its life. All the time it must be transporting water from its roots to the rest of the plant. Many plants show movements of their leaves or flowers, which of course need energy to be carried out. White clover, for instance, and wood-sorrel fold their leaves up at night and spread them open again by day; this is to prevent the plant losing too much water through the

leaves. The Sensitive Plant folds all its leaves up at a touch. Other leaves, like those of the sundew we described in Book I, catch little insects by means of their movements.

Flowers, too, often close up at night or in wet weather. This is to prevent the pollen getting damp: we shall explain about pollen later in this chapter. The dandelion and goatsbeard and other flowers of this kind close right up at night. The scarlet pimpernel is sometimes called Poor Man's Weather-glass, because, in moist weather, not only does it close its petals, but the flower-stalk bends right over so as to hang the flower upside-down with its stamens safely protected from any rain that may fall.

Energy, too, is needed for growth. During growth the roots must force their way through the soil, the stem must lift itself into the air against the force of gravity. Think of a big tree that has just been cut down. It weighs perhaps thirty or forty tons, and yet all that weight was lifted up into the sky by the plant itself.

The Differences between Plants and Animals

Through these experiments we have found out a number of separate facts about the way a plant works. Now, with the aid of what they have shown us, let us try to make a general picture of what plants do and how they live. We shall find that this helps us to answer the question with which we started this chapter, why the construction of a plant is so different from that of an animal.

In the first place, then, green plants do not eat at all, in the ordinary sense of the word. They build themselves up from the simple raw materials. These are carbon dioxide, oxygen, water, and various simple chemical com-

pounds of the same general type as ordinary salt, dissolved in the water. In order to get the carbon out of carbon dioxide, and to build it up into food, the plant needs energy: and this it gets from light. The really big difference between green plants and animals is in the nature of their food. Plants build up their food from raw materials: animals eat food which has already been built up.

The food-materials that the plant needs have to be got from two quite separate places. The water and the salts are in the soil: the carbon dioxide and oxygen are in the air. So an obvious difference between a plant and an animal is that the plant does not take all its food in at one place: it has no mouth. It takes some of its food-materials out of the earth with its roots, the rest out of the air with its leaves.

The next point to remember is that, except in a few places, all the food-materials which a plant needs are to be found everywhere. Above ground and out of doors there are always oxygen and carbon dioxide in the air, and the amount of them hardly varies in the least all over the world's surface. There is always light, too, for at least half the year. The supply of water and salts is not quite so universal, and it varies much more from place to place. However, except in very desert regions, there is always some water in the soil not too far down for plants to get it, even if it is sometimes a long way below the surface; and when there is water, it always has dissolved in it some supply of the salts which the plant wants, except in a few places like very high mountains or the arctic snowfields, where some of the salts may be missing, or in others, like some salt marshes, where there are the wrong sorts of salts.

So wherever plants can live at all, their food-materials are

all round them. They do not have to move about to find their food like animals, and so the most convenient thing is for them to be fixed in one place. Instead of moving about after food, they spread their roots out in the earth and their leaves in the air. They do not eat their food, they absorb it. As the water which the roots suck up is everywhere in the soil, the roots branch and branch so as to penetrate in all directions with their tiny root-hairs. The leaves, on the other hand, are doing work which needs the energy of light, and light comes mainly from one direction. So they are generally spread out flat, exposing as much surface as possible to the direction from which most of the light comes: and the leaves grow so that one does not cover another, but as many of them as possible are exposed to the light.

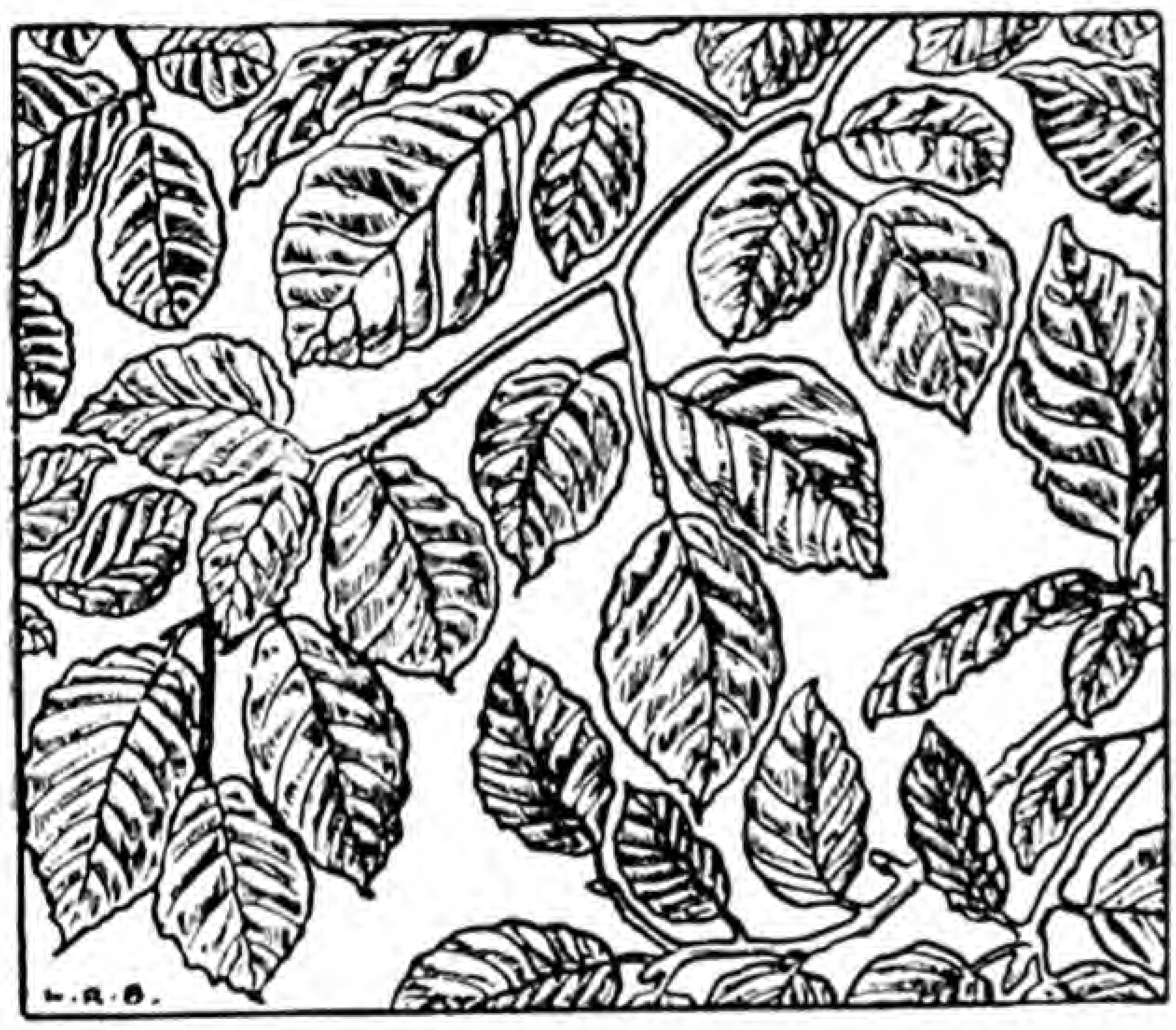


FIG. 103.—*Part of a branch of a beech, seen from above. The leaves are spread flat to catch the light, and are arranged so as to overlap each other as little as possible.*

As plants are fixed they of course do not need muscles for moving themselves about, nor a brain and nervous system to work the muscles, nor complicated sense-organs to tell them where to go and what to avoid. Nor do they need any system of levers on which the muscles can pull to produce the right kind of movements. In animals, as we know, this system of levers is provided by the skeleton; so we might think that plants needed no skeleton. But that would be to forget that the skeleton, in all animals

which live out of water, does something else of very great importance: it supports them and prevents them collapsing in a squashy mass. Plants which live out of water need to be supported as much as animals; and so we find that they have a skeleton, though this is entirely for support, and has no joints and leverage arrangements in it. The supporting skeleton is the woody part of the plant. Without it land plants could only be very tiny and not even a buttercup stem could stand up; it is owing to its wonderful strength and elasticity that some plants, like the big trees of California, which are a kind of cone-bearing tree called Sequoia, can grow to three or even four hundred feet high.

There are still other consequences of the one big difference between plants and animals, which is the difference in their food. One consequence concerns digestion. Plants build up their bodies out of very simple raw materials. Animals get their food second-hand; it is always already built up, and consists either of plants, or of animals which in their turn have fed on plants. This second-hand food is much more complicated chemically than the simple food-materials of a green plant. In fact, it is so complicated that it has to go through all sorts of processes before it can even get fully inside the animal, into its blood, and serve as raw materials for building up the animal's own living substance. All these processes are called *digestion*. Our teeth and gullet, our stomach and intestines, our liver and sweetbread and other glands, all have to exist in order that our digestion shall go on; and all sorts of pains and diseases come from our digestions being out of order.

A plant, on the other hand, has not got any digestion to do. So it needs nothing to correspond with our diges-

tive tube and digestive glands. A plant has no stomach or intestine or sweetbread or mouth-watering glands. What it does need, however, is a good arrangement for carrying things from one part of itself to another. It has to build up its food from simple raw materials; and these raw materials are being brought in at two different places—one set in the roots, another set in the leaves. The two sets of raw materials must be brought to the same place to be built up into food, just as the different parts of motor-cars may be made in different factories, and have all to be brought together into one workshop to be assembled into the finished product.

As a matter of fact, the place where the plant assembles its raw materials into food is in the leaves. So first there must be an arrangement for bringing the *sap*, as we call the water from the roots with its salts dissolved in it, up to the leaves. This is provided by the constant current of sap up the stem. As a matter of fact, it travels through the woody part of the stem. If you look at this under a microscope, you will see that it has in it thousands of very tiny hollow pipes: it is along these that the water travels. The plant is all the time sucking water out of the soil and forcing it out into the air through the millions of tiny breathing-holes in its leaves. Then, once the food is formed, it has to be taken all over the plant to feed the various parts. This is done by another set of pipes which lie nearer the outside of the stem than the little water-pipes which make the wood. This other set of pipes is called the *bast*. The bast lies just below the bark, and will come off with it. If you cut a ring in the bark all round a tree, the food cannot get down to the roots, and the tree will die. This is called ring-barking. Sometimes rabbits and other animals gnaw at the trees so as to ring-bark them

and kill them; that is why young trees are often protected by wire netting.

The "veins" in a leaf also have wood-pipes and bast-pipes in them, and these join on to the wood and the bast in the stem. They take water to the different parts of a leaf, and transport food away towards the stem.

Finally, the plant needs to store some of its manufactured food as provision against a rainy day (or it would be better to say against a dry day or a cold day, as rainy days are generally good days for plants). Some plants only live for one season, and die the same year they began to live: plants like this are called *annuals*. Other plants live for more than one season: these are called *perennials*, or if they only live two years, *biennials*. In annual plants not much of a reserve store is needed, and you simply find a certain amount of starch and other food-substances in the leaves and stem. But in biennial and perennial plants, whose stem and leaves die down in the winter and then shoot up again next spring, a big store is needed to make the new stem and leaves; you will find that parts of such plants are used only for storehouses and are swollen with starch or other reserve material. The bulb of an onion or a snowdrop is a good example. Here some of the leaves, instead of being green and growing in the air, are kept underground and serve as food-stores: they are thick and white, and packed with food-material. Most of a bulb is made of these food-leaves; you can

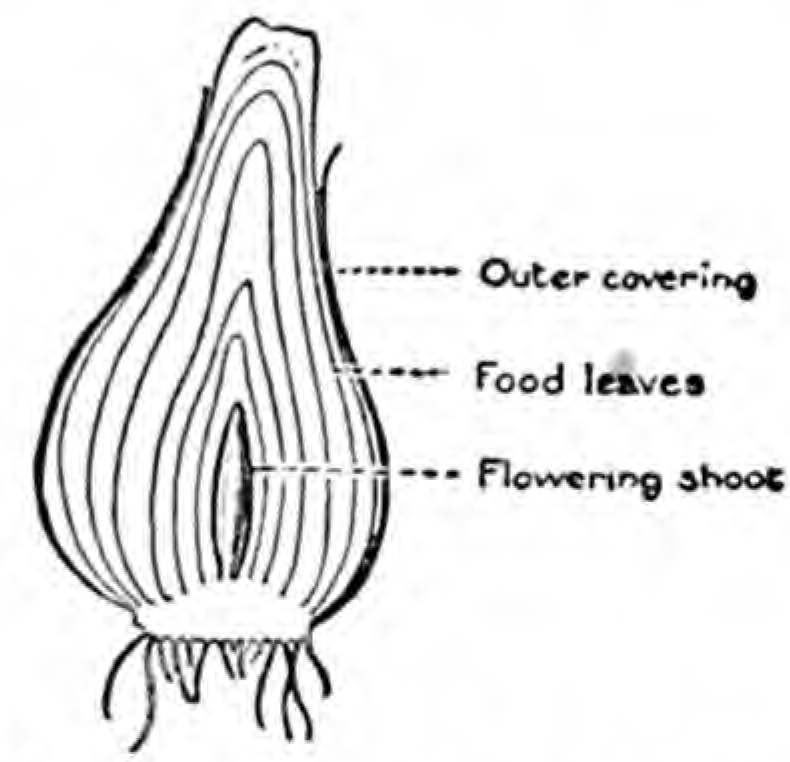


FIG. 104.—*A tulip bulb cut in half to show the fleshy food-leaves on which the plant will live until the new shoot has grown out.*

strip off one after another of them, and finally you will find the next year's shoot inside, waiting to be sprouted out. Carrots and turnips provide another example: here the food is stored in the root and makes it swell.

Another place where food is often stored is in seeds, so that when the young plant begins to sprout, it can live on these stores until its leaves and roots are properly grown and it can make enough food for itself. We shall speak more of this in the next chapter.

These are all the parts which the individual plant needs. But besides these it has to reproduce itself. For this it grows its flowers, where the seeds of next year's plants are made. We shall explain later on how this happens.

A plant, then, like an animal, is constructed to meet the needs of its life: and the differences between the way animals and plants are constructed all come back to the one big difference in the way they live. Because plants can make their food from substances in the air or the soil they are fixed, and have roots and leaves and transport systems of wood and bast pipes. Because animals have to find their food ready-made and then digest it they have to have muscles and limbs, nerves and brain and sense-organs, mouth and digestive system, all of which plants can do without.

Flowers and Seeds

Perhaps it will surprise you to learn that the bright colours and striking shapes and sweet scents of flowers are also a consequence of plants being fixed in one place. If plants moved about like animals, they would not have beautiful flowers such as now exist. Why this is so we shall explain shortly: but first we must study a flower to

see how it is made, and what its different parts do. Almost all flowers are constructed in the same general way and have the same kind of parts. But it is much easier to see the different parts and understand the construction in some plants than in others. For instance, a daisy and an orchis are difficult flowers to study, while a lily or a wallflower is much easier. Among common flowers perhaps buttercups are the easiest to understand; so we will take a buttercup as our example, although many other sorts would do almost as well—for instance, a poppy (a single-flowered, not a double-flowered sort). In the middle of the flower are a number of little green objects, shaped rather like flasks. These, taken all together, are called the *ovary* (if you want a name for the separate objects, they are called *carpels*). If you cut one open carefully you will find it is hollow, and if you look with a magnifying glass you can see a tiny oval green object inside, attached to the walls of the flask. This is called the *ovule*; it is the part which will grow into the buttercup's seed. So the centre part of the flower is the seed-making part. If you are looking at a poppy instead of a buttercup, you will find that instead of there being many separate parts, they are all joined into a single large ovary, with a great many ovules growing inside it.

Round the ovary is a ring of little stalks with swollen yellow tips. These are called the *stamens*. When the flower is in full bloom the swollen parts burst open and a yellow dust called *pollen* comes out. It is the pollen which makes your nose yellow when you smell flowers: madonna lilies, for instance, will leave a lot of pollen on your nose. If you look at a little pollen under the microscope you will see that it consists of thousands of tiny round yellow balls. These we call *pollen-grains*. It is

one of the most interesting discoveries about plants that the seeds will not develop unless some pollen reaches them. Just how the pollen gets to the future seeds is very wonderful: we will speak of it later.

Round the stamens, again, comes the bright-coloured part of the flower. In buttercups this consists of five yellow shiny parts, called *petals*. In a wild poppy there are four petals, and they are red: in some other flowers, like sweet peas or violets, the petals are joined together at their base to form a tube. If you pull off one of the petals, you will see a little swelling near where it is joined to the rest of the flower. This is what makes the sweet juice (called *nectar*) which bees collect and turn into honey; and the bright colour of the petals is to attract bees and other insects. Then, beyond the petals, right on the outside, there is a row of green, rather leaf-like parts. These are called *sepals*. Once the flower has opened, they have nothing special to do: but if you look at a flower in bud, you will see that all the rest of the flower is tightly wrapped up inside the sepals. The sepals protect the other parts of the flower until they are fully grown. All these different parts are joined on to the cone-shaped top of the flower-stalk.

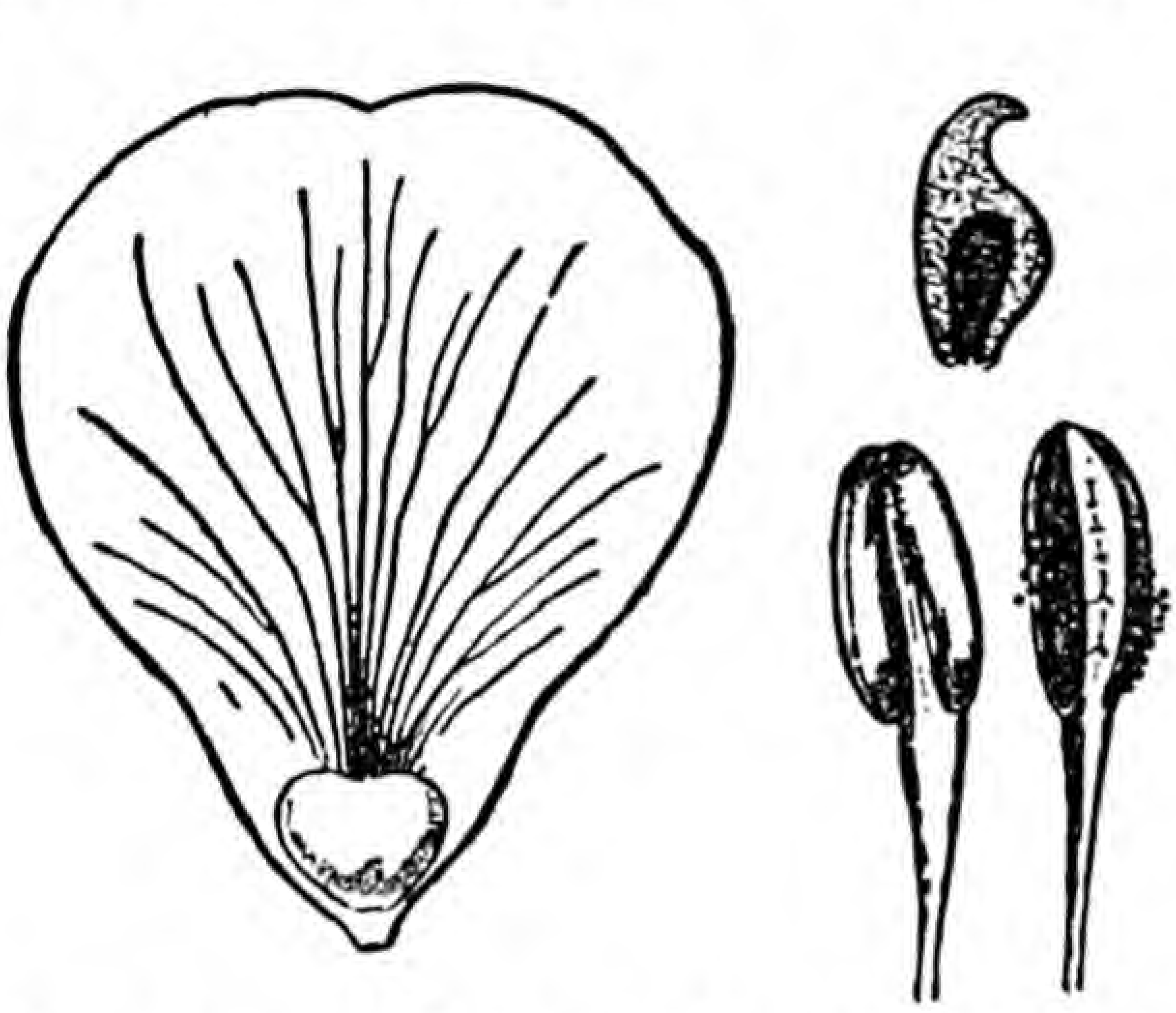


FIG. 105.—*Parts of a buttercup flower. Left, a petal: at its base is the swelling where the nectar is made. Right, above, a carpel of the ovary cut in two, showing its sticky top, and an ovule inside. Right, below, two stamens: one of them has burst open and the pollen-grains are coming out.*

The main business of the flower is to produce seeds. But it can only do this in certain conditions. If you tie a fine paper bag over a buttercup flower, after first cutting out the stamens before their pollen is ripe, it will never produce seeds. If you just cut the stamens out and do not tie the flower up, it will produce seeds. And if you dust the ovary with pollen from another buttercup plant (a fine paint-brush is a good thing to use for the dusting), it will still produce seeds, even if you first cut its own stamens out and then tie it up in paper after dusting pollen on its ovary.

What do these experiments tell us? First, that pollen must get to the ovaries if the seeds are to develop; and secondly, that even if the flower's own stamens are cut out, pollen from other flowers can somehow get on to the ovaries, provided that the flower is not tied up.

Let us first look into this matter of the pollen. How does it make the seeds develop? First of all, the pollen can grow. If you make up a solution of cane-sugar in water and put a little pollen in it, and then after a few hours look at a drop under the microscope, you will find that the pollen-grains have sprouted and sent out long thin outgrowths. They use the cane-sugar as food-material for this growth. Different kinds of pollen need different strengths of sugar. The pollen of wild hyacinths or bluebells, for instance, grows best in a 10 per cent. solution of cane-sugar. The outgrowths are generally called pollen-tubes, although they are not really hollow like a tube, but made of living substance throughout.

The ovary of a plant has one or more sticky projecting tips on it. Accordingly in actual life, if some pollen is dusted on a plant's ovary, some of it will stick. Then the pollen-grains will sprout out their little tubes, and the

tubes will grow down inside the ovary, until eventually they reach the ovule or future seed. They grow right into the ovule, and inside it a process called *fertilization* takes place. The details can only be studied with a good microscope and are very complicated. The main thing that happens is that part of the living substance of one pollen-grain joins with part of the substance of the ovule; and the importance of the process is that without it the ovule can never grow into a seed. If you look inside a number of pea-pods, you will now and again see, among the nice round peas, which are the ripening seeds, a little shrivelled object. This is an ovule which, owing to some chance or other, has not been entered by a pollen-tube, and so has never been able to grow.

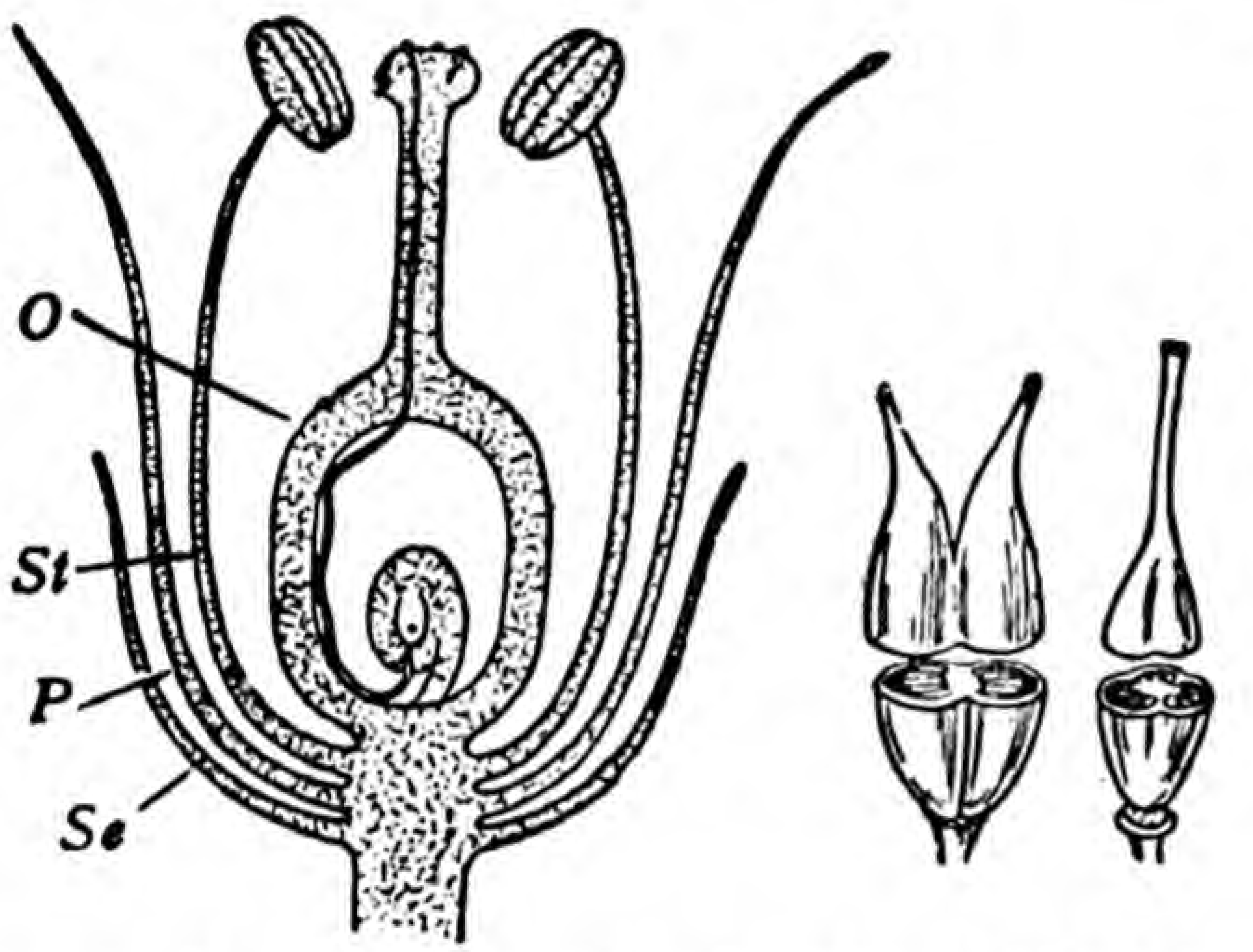


FIG. 106.—*How ovules develop. Left, diagram of a flower with sepals (Se), petals (P), stamens (St), and ovary (O). Some pollen-grains are on the tip of the ovary, and one has sent down a pollen-tube to fertilize the ovule. Right, an ovary made from two carpels joined together (saxifrage), and one made from three carpels (St. John's wort). The ovules are seen inside.*

As the plant cannot develop seeds unless pollen reaches the ovules in the ovaries, there must be arrangements for getting the pollen on to the sticky tops of the ovaries, or *pollination* as it is generally called. You might think that it would be easy to have the stamens growing so that when they were ripe and burst open, the pollen simply fell on to the ovaries. This does actually happen in some plants. But

there is a general rule in nature (though we do not yet altogether understand either the rule or the meaning of the exceptions to it), that it is better for fertilization to be with pollen from another plant than with the plant's own pollen. So in most flowers there is still something else to be done to make sure that the seeds shall develop—there must be arrangements to get the fertilizing pollen brought from another plant.

The simplest way to do this would be to use the winds to carry the pollen; and this is what a great many plants do. Hazels and nettles, grass and corn, pines and firs, are examples (Fig. 111). These plants all have their flowers arranged so that the pollen can be easily shaken out by the breeze: the dangling "lamb's-tail" catkins of hazel-bushes are a good example. Though this is a very simple method, it is also very wasteful. It is pure accident if a pollen-grain floats on to the sticky tip of an ovary. The chances against any one grain doing this are enormous, and so an enormous number of pollen-grains have to be provided. If you shake a pine-tree when its pollen is just ripe, a thick cloud of golden dust will float away, all made of microscopic pollen-grains; the total number on a big tree will run into tens of millions.

This way of getting the pollen to the ovaries is as if you were to drop circulars out of an aeroplane and trust to their getting to the right people. Actually with circulars we see that they get to their destination by having a postman deliver them at the right address. Many plants employ insects and birds as postmen for their pollen.

Insects and Flowers

Bees and butterflies and moths are the insects which do most of the work of taking pollen from flower to

flower. If you look at a bee at work on a flower, you will see that it has a long tongue or proboscis for sucking up nectar. Under the microscope, this can be seen to be hollow and to have a little spoon-like arrangement at the tip. Butterflies and moths have even more remarkable tongues. They are so long that they have to be rolled up when they are not being used. Some kinds of hawk-moths have tongues nearly a foot long; these are used to reach to the bottom of the long spurs on certain orchid flowers, where the flower keeps its nectar safe from all other creatures whose tongues are not long enough to get at it.

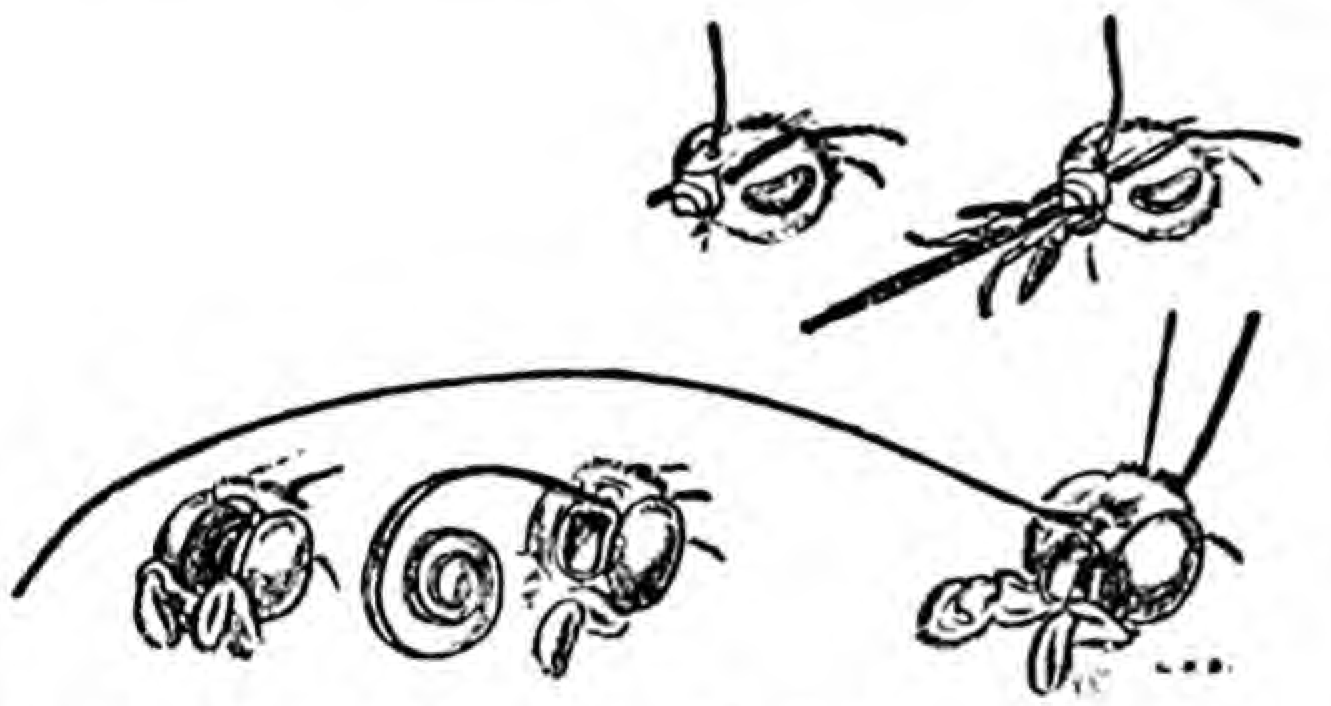


FIG. 107.—*Insects which live on nectar from flowers have long tongues. Above, the head of a bee with tongue folded up and pushed out. Below, the head of a hawk-moth with tongue rolled up and packed away, half unrolled, and quite unrolled.*

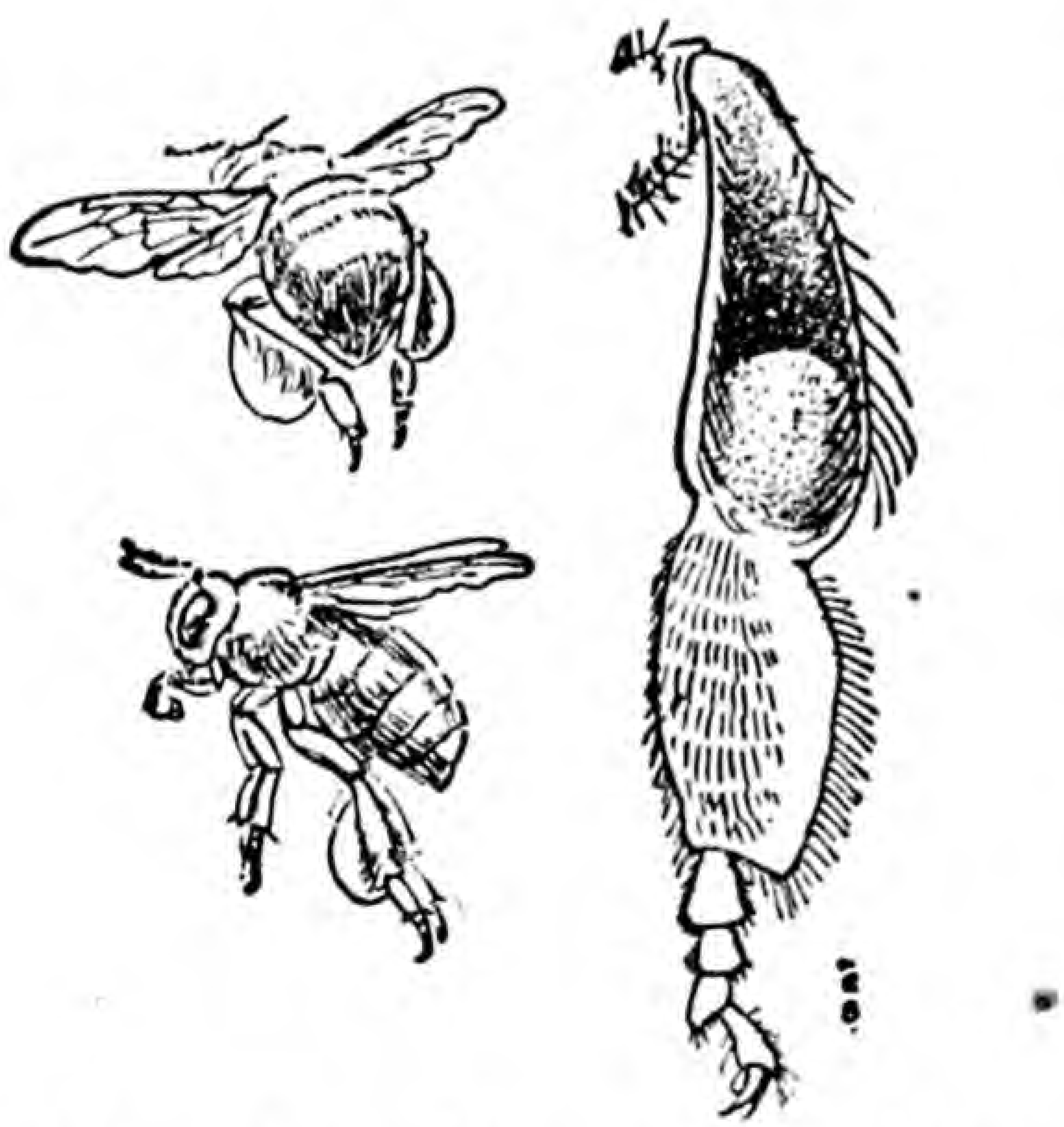


FIG. 108.—*Two bees with packets of pollen on their legs. Right, the hind leg of a bee to show the beaked arrangement for holding the pollen.*

Butterflies and moths feed on nectar alone. But bees use pollen too. If you watch a bee visiting flowers, you will see that she has little yellow blobs on her hind legs. These

are masses of pollen which she is carrying in a sort of basket of hairs. The pollen is used as an important part of the food of the young bees when they are still grubs.

So it is clear that the butterflies and the bees get something out of the plants; in fact, they depend entirely on what they find in the flowers for their food. But how do the plants get anything in return? What happens is this. The insect, poking its head into the flower, becomes dusted with pollen: and when it visits another flower it leaves some of this pollen on the sticky tip of the ovary. Thus the nectar and the extra pollen which the plant gives away to the bee are really bribes to keep the bee going busily from flower to flower, and so transporting pollen from the stamens of one flower to fertilize the ovules of another.

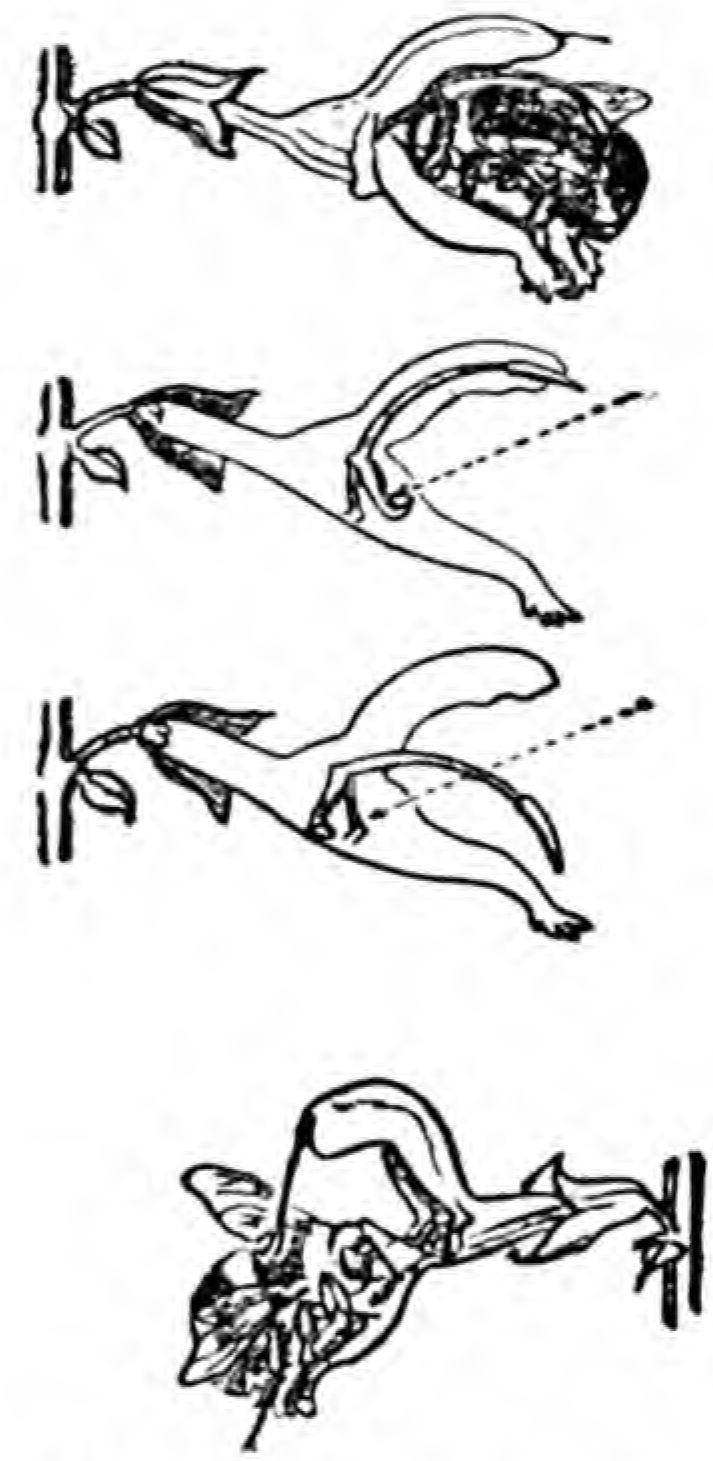


FIG. 109.—*How sage-flowers are pollinated. Above, a bee sucking nectar from a flower and getting dusted with pollen from the stamens. The tip of the ovary has hardly grown out of the top of the flower. Centre, to show the lever arrangement by which the bee pushes the stamen down on to her own back. Below, a bee visiting an older flower. The tip of the ovary has grown down so that the bee cannot help brushing her back against it.*

The arrangements by which the flowers make certain that the insect shall get dusted with pollen and that this pollen shall be left on the tip of the ovaries of another flower are often very ingenious. If, for instance, you look at the flower of a sage-plant, you will find that the stamens are made like little levers.

As the bee pokes its head into the flower, it cannot help pushing against the short arms of the levers, and this brings the pollen-sacs, which are at the tips of the long arms, down on to its back, which gets dusted with pollen. The sticky tip of the ovary is curved right over, so that it will touch the back of a bee that is poking about for nectar; and so when the bee visits another flower some of the pollen on its back sticks to the tip of the ovary.

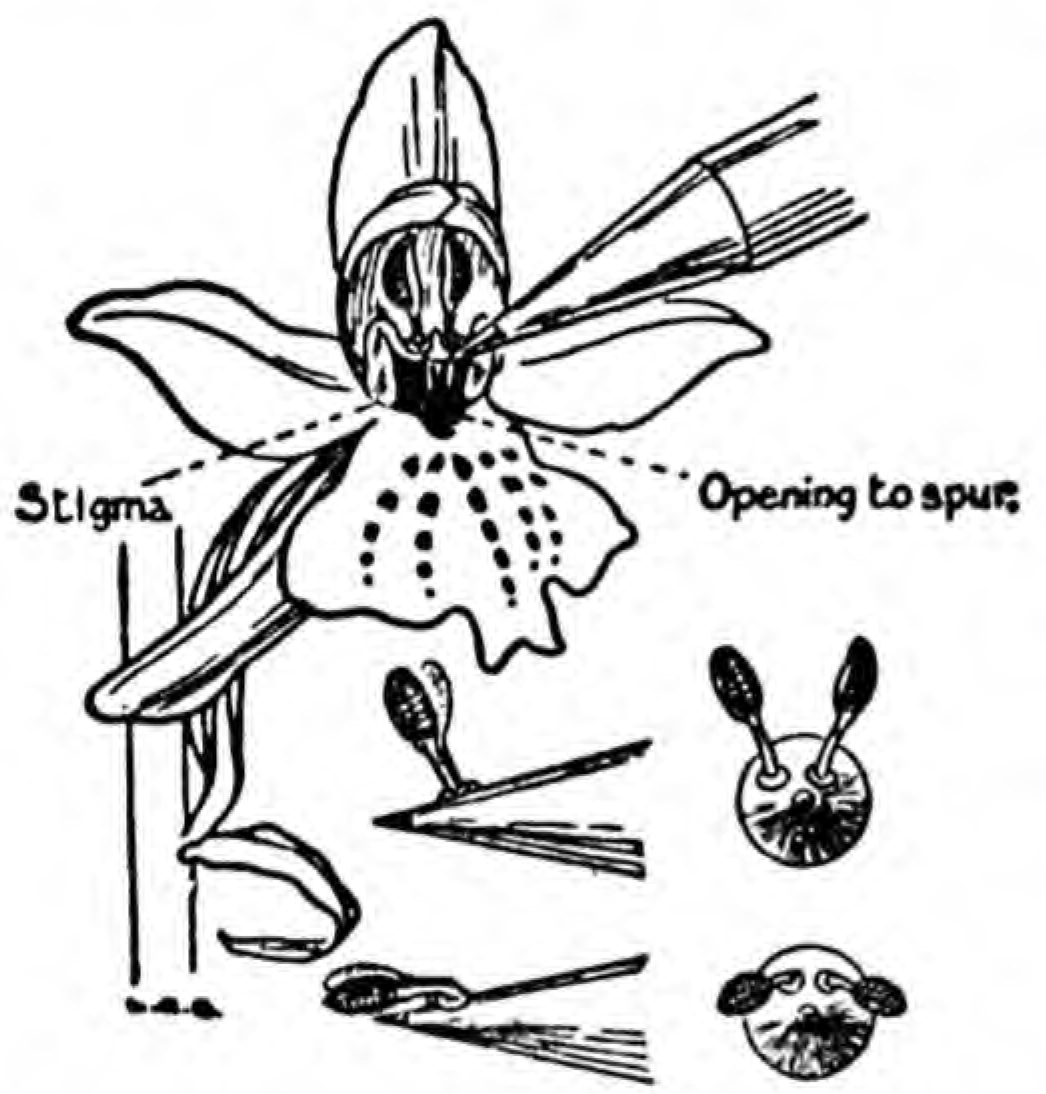


FIG. 110.—*How an orchis is pollinated* (Orchis mascula). *The pollen-masses stick to a pencil (or to a bee's head) and bend so as to be opposite the sticky tips of the ovary (stigma) when the pencil (or bee's head) is pushed into the next flower.*

There is a family of flowers, often very beautiful, called orchises, or orchids. Some of these, like the spotted orchis and the meadow orchis, are common in England. Perhaps they have the most wonderful arrangement of any British flowers. The pollen here is all stuck together into two little club-shaped masses; each of these is kept moist inside a sheath, and the only part outside the sheath is a very sticky pad. If you poke the point of a pencil into the tube of an orchis flower, the two pads stick to it, and when you take the pencil out the pollen-masses are torn out of their sheaths and come with it.

They are so made that, as they dry, they bend down and sideways. As soon as they are pulled out of their sheaths they begin to dry, and in the course of about half a minute you can watch them gradually altering their position. If

after this you poke the pencil into the tube of another flower, you will find that the tips of the pollen-masses now come up against two sticky patches, which, as a matter of fact, are the tips of the ovary. Some of the pollen is left behind here, and grows down to fertilize the ovules. Moths often visit these orchis flowers; the pollen-masses stick to the moth's proboscis just as they did to your pencil-point, and before the moth has got to another flower they have bent over into the right position for fertilizing the ovules of this flower.

Besides arrangements of this sort, it is necessary to have arrangements for preventing pollen from being brought to the ovaries of the same flower. The orchis shows one way of doing this. But the commonest method is to have the stamens and the ovaries ripen at different times. In the sage-flower, for instance, whose pollen-dusting arrangements we just mentioned, the sticky tip of the ovary is forked. But during the time that the stamens are ripe it is closed up tight, and only later does it open, so pollen can never reach the ovaries of the same flower.

Another way is to have the stamens and ovaries on separate plants. This is very common in plants which use the wind for pollination, like hazels or pine-trees, and is also found in some which use insects for pollination, such as willows.

Some plants, on the other hand, prefer to have their ovules fertilized by pollen from the same flower rather than not to be fertilized at all. Dandelions, for instance, are generally pollinated by insects which bring pollen from another flower. But if this does not happen, the sticky tip of the ovary bends over until it touches the stamens, and so the flower becomes self-pollinating and fertilizes its own ovules.

If you look at a number of flowers, some of which are pollinated by wind and others by insects, you will see a great difference between them. The wind-pollinated flowers are usually small and green, and are never brightly coloured; they often have no petals, or the petals are tiny; they have no sweet scent and no nectar. Think of nettles, grasses, or oak-trees. The insect-pollinated flowers, on the other hand, are usually brightly coloured, with large

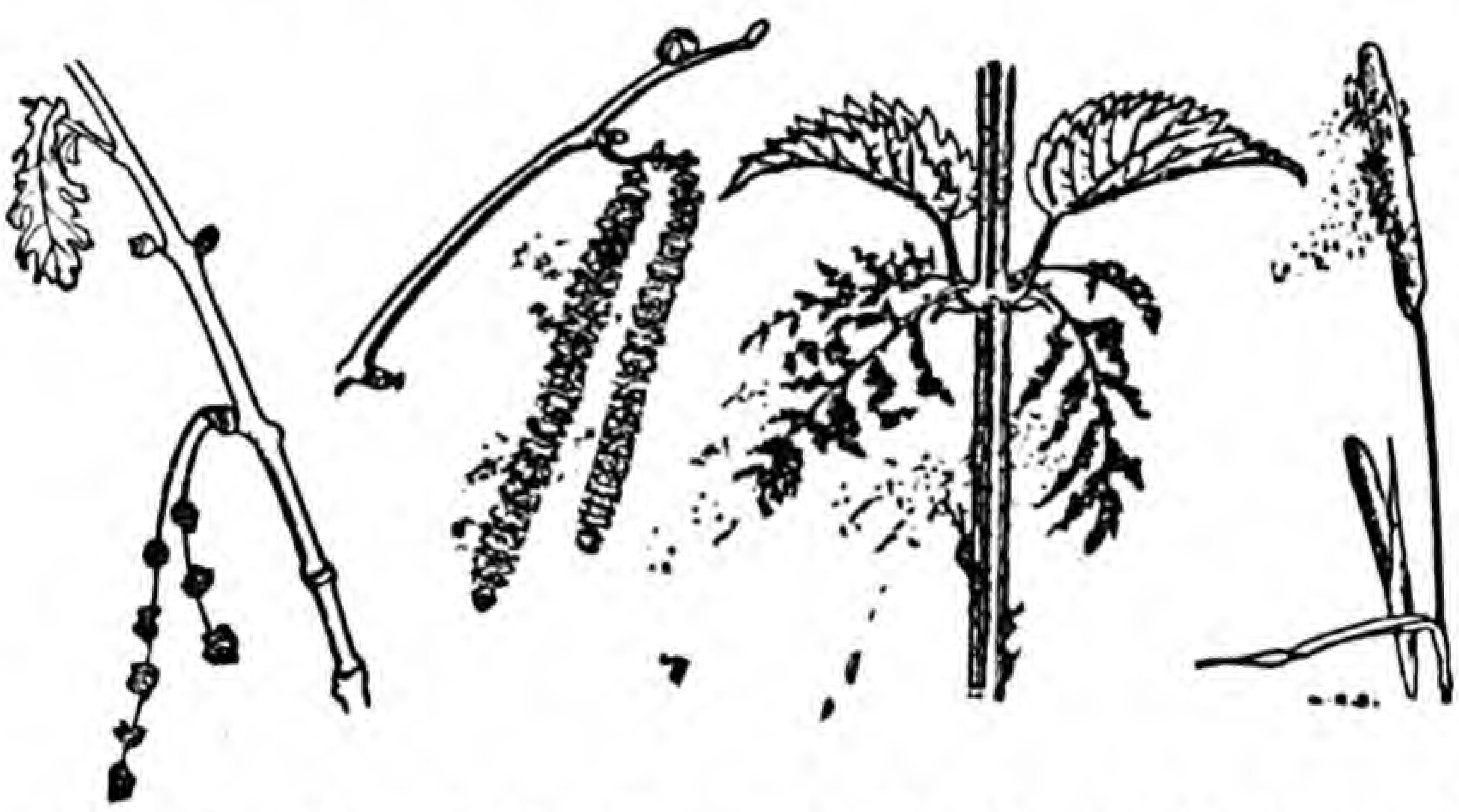


FIG. 111.—*Plants whose pollen is carried by the wind. From left to right: oak, hazel, nettle, Timothy grass. The hazel has the stamens in one sort of flower (the catkins), and the ovaries in another sort, seen on the left.*

petals; they almost always have nectar, and are often scented. Think of roses, lilies, honeysuckle, or apple-trees.

The nectar is a bribe or payment to the insects; and the bright colour and the scent are advertisements, so that the insects can recognise the flowers from far off, and generally keep on working at one kind of flower for a considerable time. If plants did not have to rely on insects to act as postmen for their pollen, they would not need the large petals, the bright colours, or the strong scents. But they would not need insects to do this job for them if they

were not fixed; and the reason they are fixed is that they do not have to move in search of their food. That is why, as we said earlier in the chapter, the fact that plants can get their raw materials from the air and the soil has led to the existence of beautiful flowers.

What is more, it has led to the existence of certain kinds of insects. Bees and butterflies, for instance, depend entirely on flowers for their livelihood. Butterflies only depend on flowers when they are fully grown; their caterpillars eat leaves. But bees are always dependent on flowers. The grown-up bee lives on nectar and honey, which is made from nectar but has much more sugar and much less water in it; and the young bees while they are grubs are fed on a mixture of honey and pollen. So bees and butterflies on the one hand and brightly coloured flowers on the other make a kind of partnership. Neither could exist if it were not for the other.

Not all bright coloured flowers are pollinated by insects. Some rely on birds instead. This only happens in the tropics. This is because birds have not learnt to store up honey and pollen like bees, nor can they hibernate like some butterflies. So birds which rely on flowers for their food must have a supply of flowers all the year round, and this can only happen where there is no cold winter season. Humming-birds and sun-birds are the chief kinds of birds which pollinate flowers. The frontispiece to Book IV (Earth and Man) gives a picture of a humming-bird visiting a flower.

Seeds and How They are Distributed

To finish the story of the plant we must deal with the seeds which develop from the ovules when they are fertilized. One thing we have already mentioned about seeds, and shall speak of again in the next chapter, and that is

that they must contain a store of reserve food-material for the baby plant to draw upon before it has grown roots and green leaves and can make its own food for itself. Sometimes there is a big store of food-material, as in a bean or a wheat-grain, a horse-chestnut or a plum-kernel; sometimes the store is small, as in the seeds of mustard and cress or poppies; but there is always something in reserve.

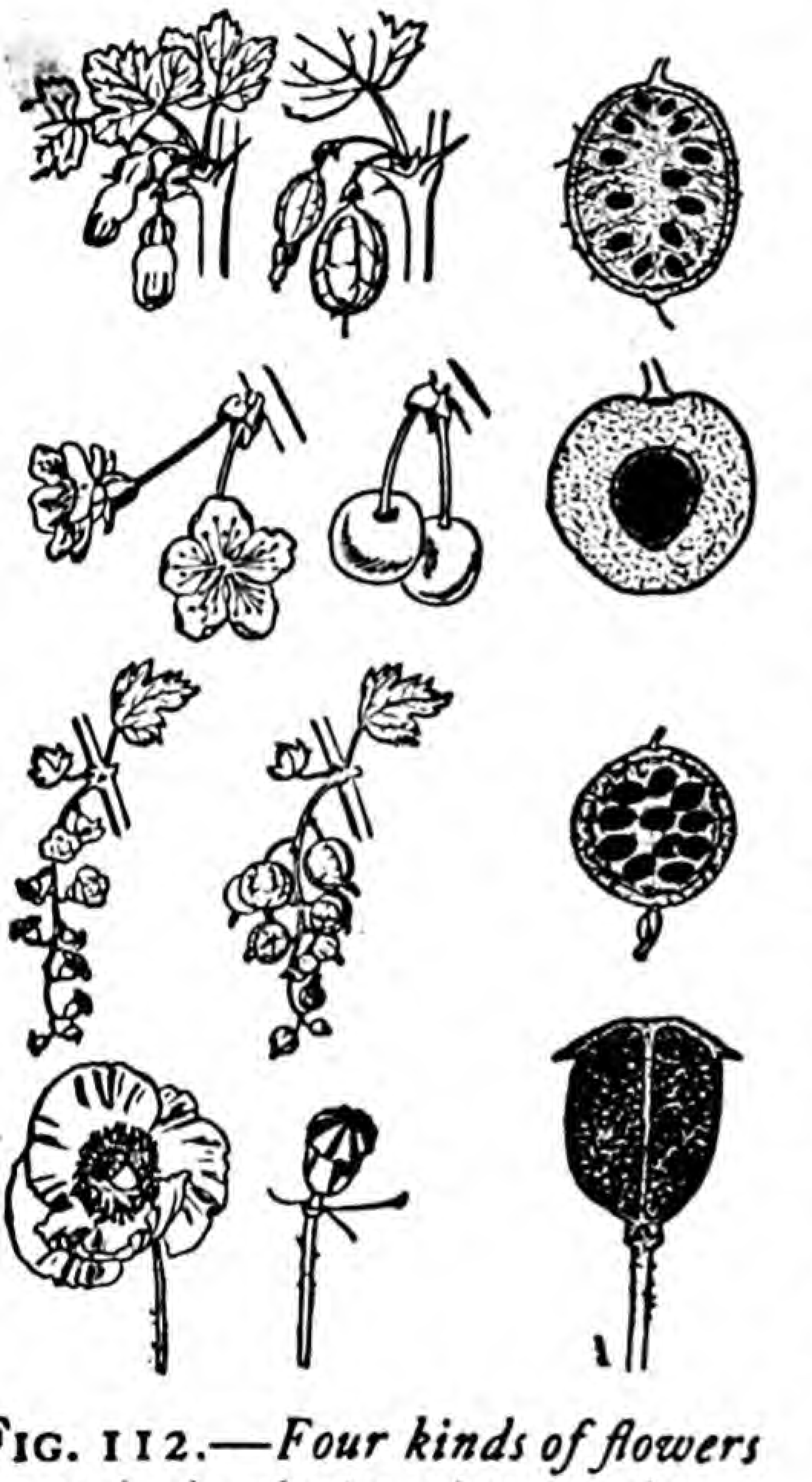


FIG. 112.—*Four kinds of flowers and the fruits they produce: gooseberries, cherries, red currants, and poppies. On the right, the fruits have been cut across to show the seeds: the seeds are in black.*

The next great necessity for seeds is protection. While the fertilized ovule is growing into the seed it is juicy and tender, and in many cases (as in beans or peas) the seed itself is soft and would make a good meal for many animals.

The ripe seed may be protected by growing a very hard outer coat: the best example of this is a Brazil-nut; the whole nut is one big seed, and the shell is its hard woody coat. But the usual method, which also protects the seeds when they are soft and young, is for the ovary which encloses the growing seeds to grow too, and to become thick and hard. When an ovary grows like this it is called a fruit. In botany, the word *fruit* does not only mean a juicy fruit which we can eat, but includes every kind of

construction which develops out of the ovary round the growing seeds; for instance, in botany a hazel-nut or an acorn is called a fruit just as much as a plum, a bean-pod just as much as an orange.

It is sometimes difficult not to mix up seeds and fruits. For instance, the whole of a Brazil-nut is a seed, while the seed of a hazel is only the kernel of the hazel-nut. The only difference is what they grow from. A seed grows out of an ovule, a fruit out of an ovary. A fruit is sometimes made out of neighbouring parts of the plant as well: for instance, what we eat in an apple is made of the enormously swollen top parts of the flower-stalk; but part or all of a fruit always comes from the ovary of the flower.

Finally, seeds must be scattered broadcast. It would never do to have them all just fall to the ground. They might be killed by being in the shade of their own parent and not getting enough light, and in any case they would be competing with it and with each other, instead of finding new places where they could grow up without so much crowding.

So plants usually have some arrangement for spreading their seeds abroad, or, as botanists generally call it, for *seed-dispersal*. Sometimes the actual arrangement concerns the seeds, sometimes the fruits; but the reason is always the same—to scatter the seedlings far and wide.

One way of dispersal is by air-transport. Dandelions and thistles are the best examples of this. Each little fruit has a parachute of fine white hairs on it, so that when it is ripe it can go sailing down the wind for long distances. Willow-herbs have a similar arrangement, but here the parachute is not on the fruits but on the seeds. Many fruits and seeds have flat "wings" or expansions which keep them from falling very fast, and so let them be carried

a certain distance by the wind before they reach the ground. For instance, gladioli and pine-trees have winged seeds, and elms and birches have winged fruits. The most ingenious type of wing is found on the fruits of maples and

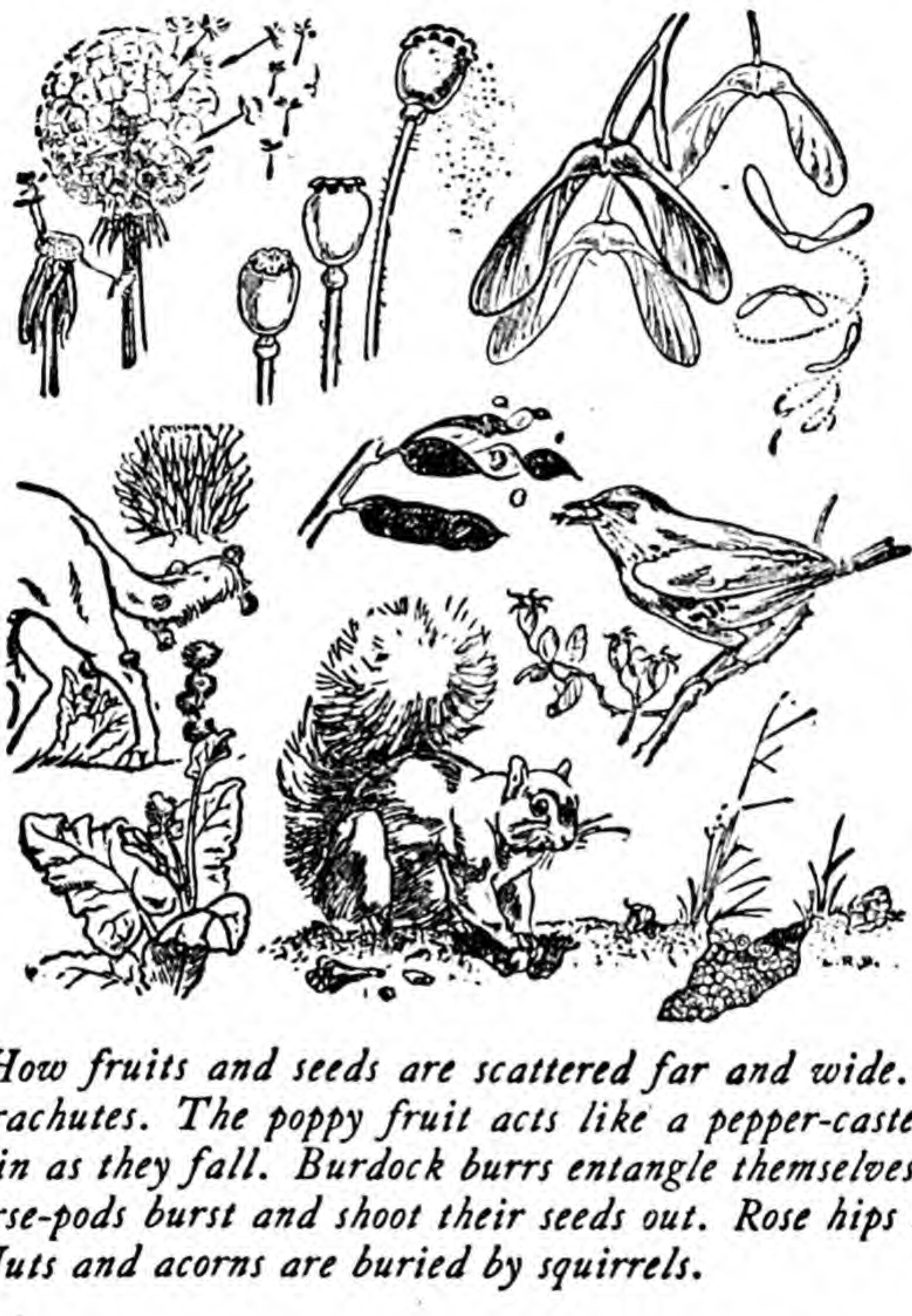


FIG. 113.—*How fruits and seeds are scattered far and wide. Dandelions have parachutes. The poppy fruit acts like a pepper-caster. Sycamore fruits spin as they fall. Burdock burrs entangle themselves in animals' fur. Gorse-pods burst and shoot their seeds out. Rose hips are eaten by birds. Nuts and acorns are buried by squirrels.*

sycamores; it is made so that the fruit spins round and round as it falls, which in its turn makes it fall more slowly.

A small amount of scattering, which is enough for plants which die after a single season, can be got by having the ripe fruit with holes in it, through which the seeds are sprinkled when there is a wind, like sugar from a

sugar-caster, or pepper from a pepper-pot. Poppies and Canterbury Bells are good examples. Sometimes the scattering is made more efficient by arranging that some sort of explosion shall take place in the fruit when it is ripe. If you are among gorse-bushes on a still, hot day in summer, you will hear a little popping sound at intervals. This is the ripe gorse-pods bursting open. As they ripen, the outside dries more quickly than the inside, and so tends to pull the two halves of the pod apart, just as would happen with two thin boards which began to warp. Eventually the warping becomes too strong, the pods burst open and their halves twist back, and the seeds are shot out to a distance of several feet. Wood-sorrel and balsam are other plants which shoot their seeds out. The balsam-pods are quite startling, for they explode in a surprising manner when they are touched.

Then a large number of fruits have arrangements for sticking to the bodies of animals. In this way they get free transport, often for long distances. The burrs of burdocks and goosegrass, and the sharp seeds of many grasses are familiar cases.

Another way of securing transport by animals is to cover the seeds with a hard shell, and then to enclose the whole in a juicy fruit. An animal or bird eats the fruit and swallows the seeds; the seeds cannot be digested because of their hard coat, and eventually pass out with the droppings, sometimes miles away from the parent plant. The hard coat gradually rots away in the damp soil, and then the seedling sprouts out. This happens with apples and their pips, plums and cherries with their stones,[1] with hips and haws and many other fruits.

[1] The seed of a plum or cherry is the kernel: the hard part of the stone is the innermost layer of the fruit.

Accordingly we see that just as the nectar of flowers serves as a bribe to insects to get them to transport pollen from flower to flower, so the eatable part of juicy fruits is a bribe to bigger animals to make them transport seeds.

Fruits of this sort are generally bright coloured: think of hips and haws, apples and cherries, grapes and plums. The bright colours act as advertisements to help the animals to find the fruits easily.

Animals, of course, have to reproduce themselves as well as plants. Some animals, such as hens and frogs and butterflies, produce eggs; others, such as rabbits and people, have babies. But we shall have to wait until a later book before dealing fully with animal reproduction.

The Usefulness of Plants

As we have already pointed out, plants can make living substance out of very simple raw materials, but animals cannot; so all animals in the long run depend on plants for their food. That is just as true of human beings as it is of cows or hens or herrings or bees. Probably some day science will find out how to build up foodstuffs out of simple substances without the help of plants. Already a beginning has been made. One scientist has made sugar out of water and carbon dioxide under the influence of light. But so far it has only been possible to make very small amounts of sugar, and at gréat expense. Until man can make sugar and other foods on a big scale and quite cheaply, he will remain as dependent on plants as any other animal. In fact, he is really more dependent. For animals in general only depend on plants for their food, while man depends on them also for many other things which he needs for a civilized existence, such as clothing, fuel, paper, and rubber.

It is worth thinking of some of the chief things which plants manufacture for man. First there is his daily bread. This he gets from wheat, rye, maize, and other *cereals*, as corn-like plants are called. These are all different kinds of grasses. What we use for bread is the reserve food-material which the plants store in the seeds for the use of the young seedling. Farmers and scientists have improved the plants until they now yield more and bigger seeds, and look quite different from the wild grasses from which they originated.

Of wheat alone a huge amount is grown by man. The wheat-fields of the world cover about 400,000 square miles, which is about three times the size of Great Britain and Ireland. The amount of wheat-grains harvested every year comes to the enormous total of between three and four thousand million tons. If man lived by bread alone this would support a sixth of the whole population of the world, even if they ate nothing else.

Instead of cereals, a large part of the human race lives chiefly on rice, which is the seed of another kind of grass that grows in wet places.

Man also uses grasses for food in another way. Instead of taking the food that they manufacture directly for his own use, he lets animals eat grass, and then gets food from the animals. All the beef and mutton we eat, all the milk, cream, butter and cheese in the world, has been produced with the help of grass. So, as rice and cereals are all special sorts of grass, we depend on grasses of different kinds for the greater part of our food supply.

Of course, there are other kinds of plants which give us important kinds of food. We need sugar-cane and a special kind of root called sugar-beet for our sugar; potatoes are

a valuable source of starchy food in temperate countries, and bananas in the tropics; beans and peas and yams are very nutritious; there are all the different kinds of vegetables, like cabbages and turnips and onions, and there are odds and ends like mushrooms and sea-weeds which people eat. But the amount of food in these only makes a small fraction of what is produced by grasses.

As a matter of fact, next to grasses, *diatoms* provide

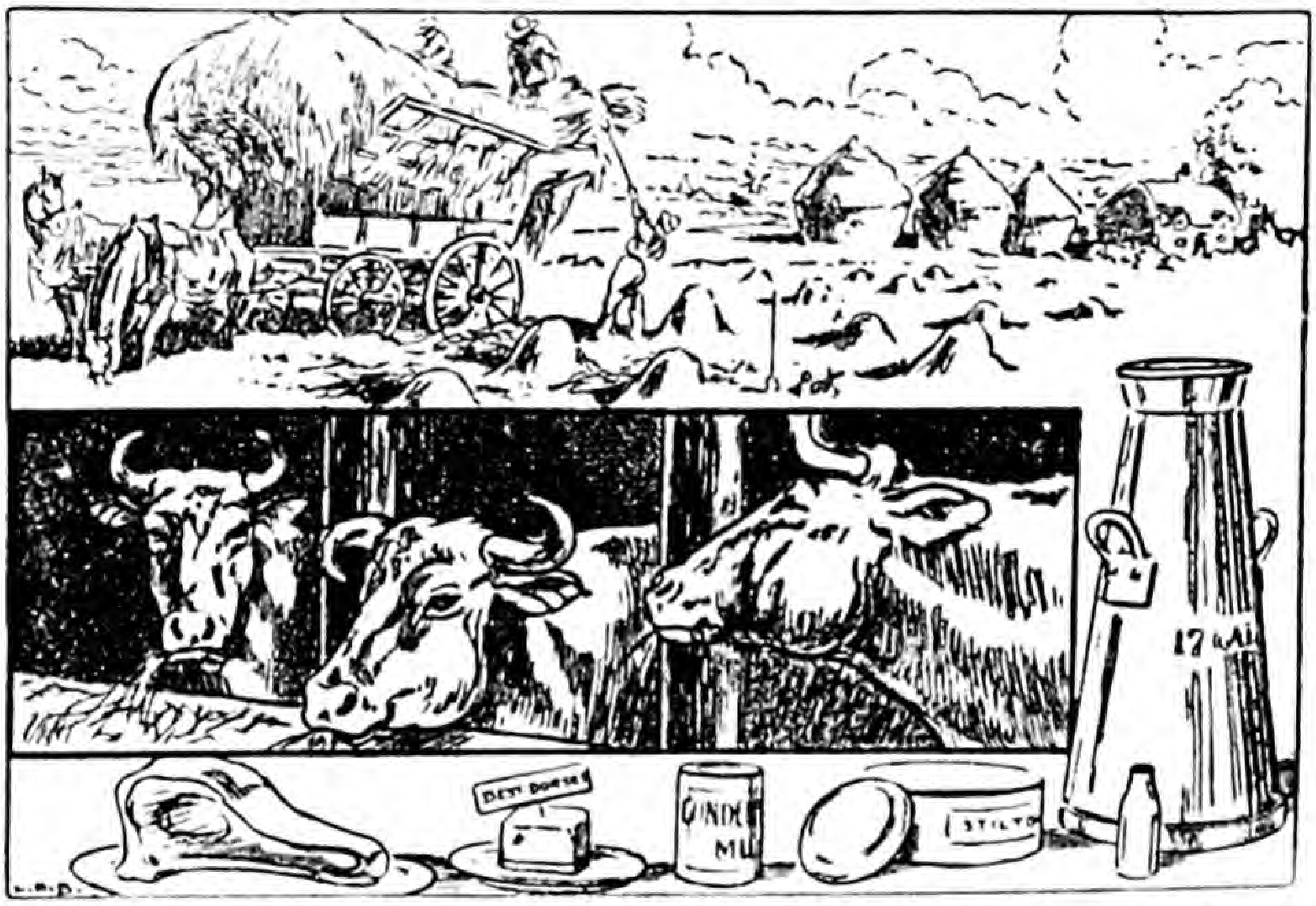


FIG. 114.—*The uses of grass. We give hay to cattle, and the cattle give us meat, butter, milk, cream, cheese, and leather.*

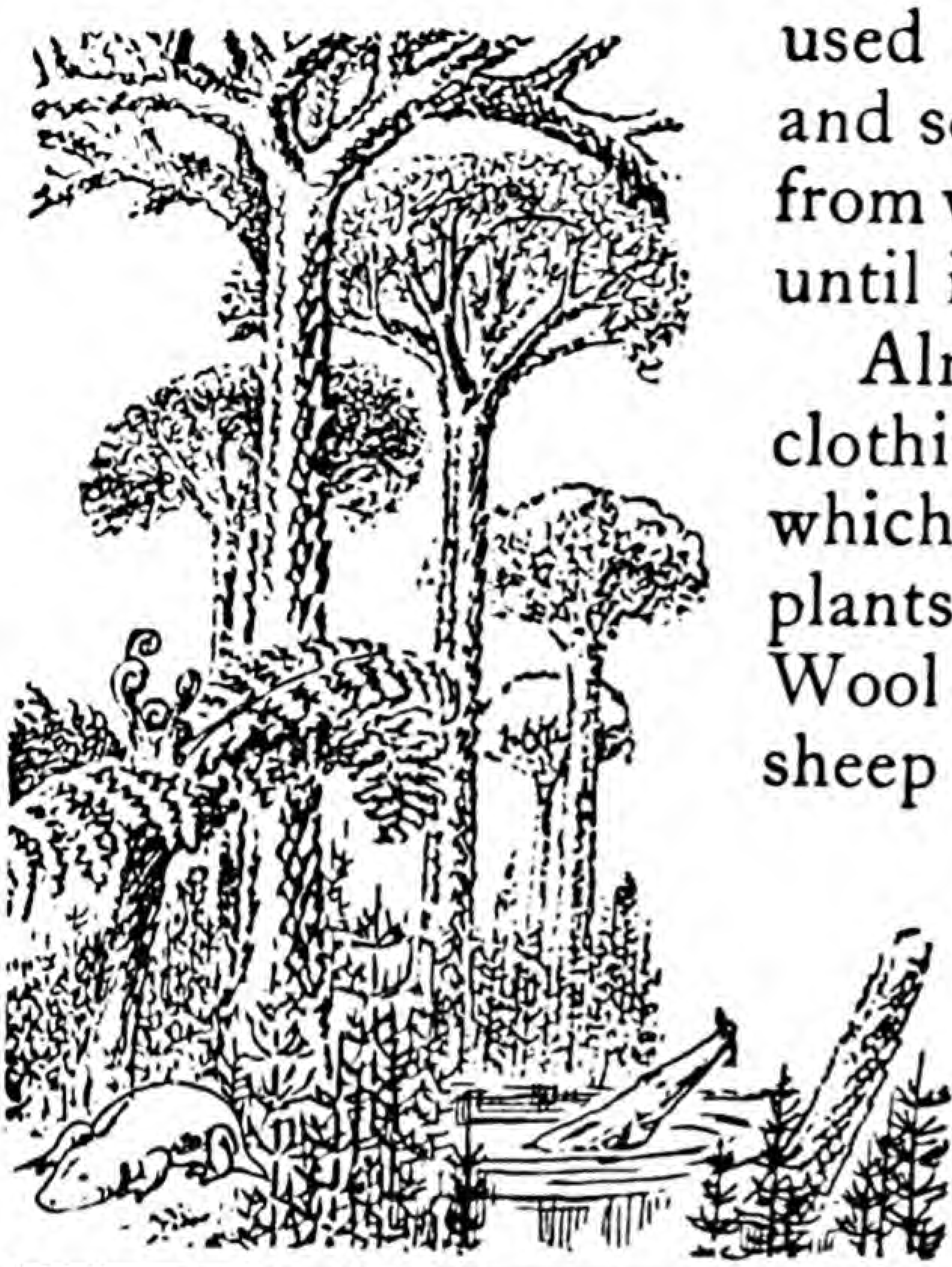
more human food than any other single kind of plant. For these microscopic water plants, as we have seen in Book I, are the main source of food supply in the sea. Without them there would be very few fish or crabs or shell-fish.

Plants also provide us with all our drinks except ordinary water and mineral waters. Tea comes from the leaves of the tea-plant; coffee and cocoa come from different kinds of fruits; beer comes from barley and

hops; cider comes from apples; wine from grapes; and there would be no milk if it were not for grass.

Of our clothes, by far the greatest part is provided directly or indirectly by plants. Linen comes from the flax-plant. Cotton is made from the long fluffy white hairs that grow on the seed of the cotton, and in nature serve as parachutes so that the seeds can be widely scattered. In the best cultivated varieties of cotton the hairs may be over two inches long. Some idea of the amount of cotton needed by man is given by the fact that for many years the average weight of this light fluffy material produced has been over ten million pounds a year. Cotton is also used for many other things. The seed yields a valuable oil, and is

FIG. 115.—*A plant which provides us with drink. Vines produce grapes, and these are made into wine or grape-juice.*



used for animal food, for soap, and so on. Artificial silk is made from wood, treated with chemicals until it turns into a pulp.

Almost all the rest of our clothing we get from animals, which means that it comes from plants one step further back. Wool and leather come, through sheep and cattle, from grass, while real silk is made by silkworms which eat mulberry leaves.

We get most of the heat we need by burning wood or coal. Wood we get from living trees, and coal comes from trees of a curious kind which grew in swamps many

FIG. 116.—*Even prehistoric plants are useful. Swamp plants which grew many millions of years ago have turned into coal, and we use the coal to drive our engines and machines.*

millions of years ago. Up till quite recently most of the power used in factories and engines came from the heat of burning coal and wood; and even today, with all our supplies of energy from petrol and oil, and from electricity generated by water power, coal and the gas made out of coal still provide a large amount of the energy used in commerce and industry. So man is dependent on plants for a great deal of the energy he needs (Fig. 116; and Book I, Fig. 61).

Up till quite recently the chief uses of wood were to build with or to burn. A certain amount of wood is treated so as to produce methyl alcohol, a kind of alcohol which cannot be drunk, but which is useful for fuel in internal combustion engines, and for dissolving varnishes and paints. But today the

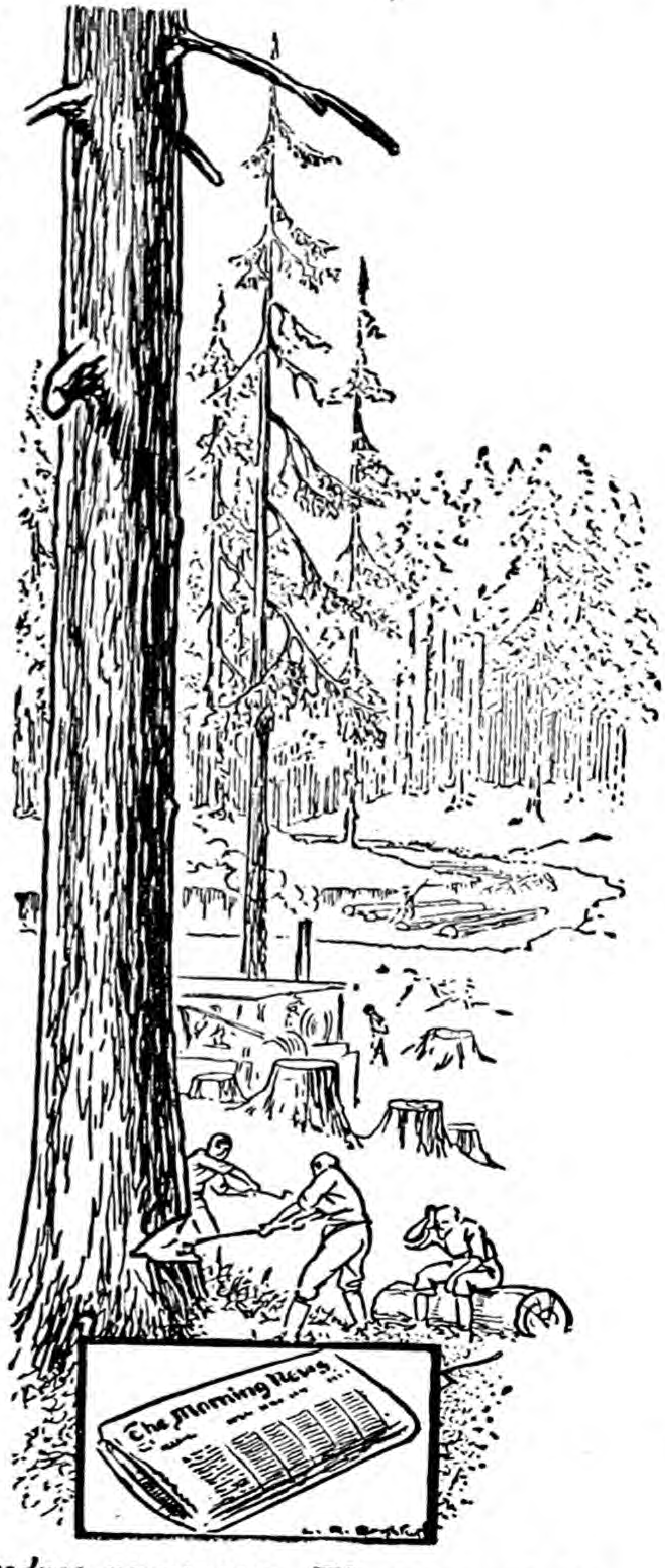
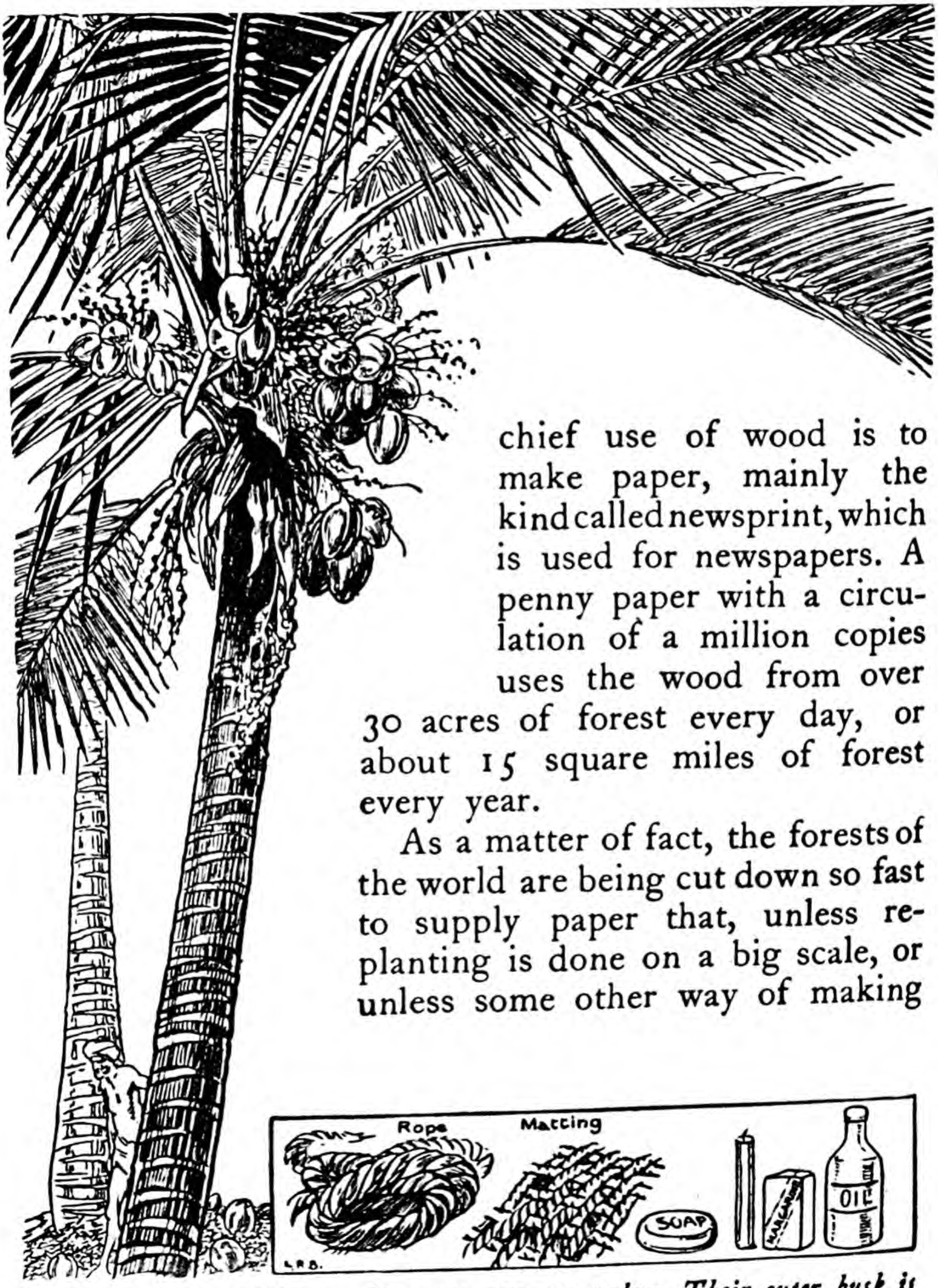


FIG. 117.—*Forests are needed to produce newspapers. The trees are cut down, sawn into logs, turned into pulp, and the pulp is made into paper.*



chief use of wood is to make paper, mainly the kind called newsprint, which is used for newspapers. A penny paper with a circulation of a million copies uses the wood from over 30 acres of forest every day, or about 15 square miles of forest every year.

As a matter of fact, the forests of the world are being cut down so fast to supply paper that, unless re-planting is done on a big scale, or unless some other way of making

FIG. 118.—*A useful tree. Coconuts grow on palms. Their outer husk is used for rope and matting, their white fleshy interior for margarine, soap, candles, and oil. The natives use the leaves for thatching their huts.*

paper is found, there will be a timber shortage in less than a hundred years.

Finally, plants give man a great many of the raw materials he needs for his manufactures. The coconut palm, for instance, is a very all-round source of supply. From the fibre round the nut, matting and coarse rope is made; the kernel, besides giving us flavouring for cakes and sweets, is used on a large scale to make soap and margarine and candles and oil. The wood is used for building and the leaves for thatching.

Rubber is another substance produced by plants, which is absolutely necessary for civilization. Rubber has a great many uses. It has for a long time been used for erasers, for goloshes and rubber boots, and for waterproofing coats. Of recent years a great deal of rubber has been turned into the hard black stuff called ebonite, and there is a big trade in rubber soles and heels for boots and shoes. A great deal of rubber and ebonite is used in electrical machinery, because these materials will not conduct electricity; but the greatest single use of rubber today is in motor tyres. Without rubber for tyres, motoring would be impossible, as there would be too much vibration. Since the war the amount of rubber produced each year has been on an average about 400,000 tons.

All this huge amount is got by "tapping" rubber-trees. A cut is made in the bark, and a milky juice flows out, which is collected in little pots fastened to the side of the tree. The milky juice is afterwards carefully dried; a curdled mass is left behind, which is rubber in the raw state.

We do not yet understand what is the use of the milky juice to the rubber plant. Many plants have a similar juice (or *latex*, as it is called), though it will not always give rubber; it is easily seen if you break the stalk of a dande-

lion flower or a wood-spurge plant. The latex has nothing to do with the sap, and is contained in a separate system of tubes. It is usually bitter-tasting, and perhaps in some cases this protects the plants against being eaten. It is interesting to remember, when we are in a motor-car, that though the rubber is so useful to us, we have not yet found out what its value is to the plant which makes it.

FIG. 119.—*Tapping a rubber-tree in Malaya. Above, berries of the rubber-tree. Below, some things made out of rubber—tennis-balls, golf-balls, motor-tyres, and rubber boots.*

We could go further with our list. Gums and resins are got, like rubber, by tapping trees. Oil for cooking comes from olives, ground-nuts, and cotton-seed; margarine is made out of various vegetable oils, especially from the nuts of a kind of palm. Cork is the bark of a kind of oak. Most rope is made from hemp, which is the supporting skeleton of the hemp plant, and a great deal is now made from the fibres of the huge spiky leaves of the sisal plant. In the old days almost all dyes were made from plants (the blue dye with which our ancient British ancestors

painted themselves was from the woad plant); and even today, when most dyes are made by chemists from coal tar, some of the most beautiful and delicate still come from plants. Perfume is made from flowers, tobacco from the leaves of the tobacco plant.

Many kinds even of the microscopic bacteria and yeasts are useful. Yeasts are needed to make beer and cider and wine, and to make bread rise. Without bacteria we should have no vinegar and no cheese; each kind of cheese owes its flavour to a particular kind of bacterium.

Thus man makes use of many kinds of plant. No part of the plant escapes. He takes the stores of food from its seeds or roots or tubers; he eats their fruits or turns the fruit-juice into drink for himself; he finds a use for their skeletons, for the gummy juices they secrete, for the perfumes of their flowers, for the coloured substances in their sap. If he cannot use them directly, he may do so indirectly, by turning out his flocks and herds to feed on their leaves.

One day, perhaps, we shall find out how to make everything we need from lifeless materials. But that is a very long time hence, and, until then, we are all entirely dependent for our existence on plants and the wonderful things they make out of the simplest raw materials.

CHAPTER VII

SOME DIFFERENT WAYS OF LIVING

Water Plants—Water Animals—Different Kinds of Surroundings in your own Country

Water Plants

IN the last chapter we described some of the chief conditions which were necessary if plants were to live healthily and spread themselves over the earth's surface. In this chapter, we will look at the way in which the animals and plants are fitted to their surroundings. The most obvious difference in surroundings is between water and land; so let us first take the difference between water plants and land plants. When we talked of green plants in general we chose a land plant as our example because land plants are more familiar. We saw how the construction of the plant is suited to the needs of its existence. It has to have roots below ground because the water and salts it needs are in the soil: it has to have leaves above ground because the oxygen and carbon dioxide it needs are in the air, and because it needs the energy of sunlight for the leaves to do their chemical work. It needs a system of pipes to take the raw materials from the roots to be assembled in the leaves into foodstuffs, and another set of pipes to take the foodstuffs all over the plant. And it needs a woody skeleton to support itself.

In the water, everything is different. The weight of a piece of living matter, which is itself largely made up of

water, is only a fraction greater than that of the same volume of water, so almost all the weight of a water plant is held up by the water. This means that it has no need of a strong skeleton. Water plants like sea-weeds or pond-weeds just collapse when taken out of water. Then a water plant does not have to get the raw materials of its food from two different places, the soil and the air. All the raw materials it needs are dissolved in the water: it is bathed in them on every side. So it can absorb water and salts all over its surface instead of through special roots; and it can be green all through, and use the energy of sunlight with all of itself instead of just with its leaves.

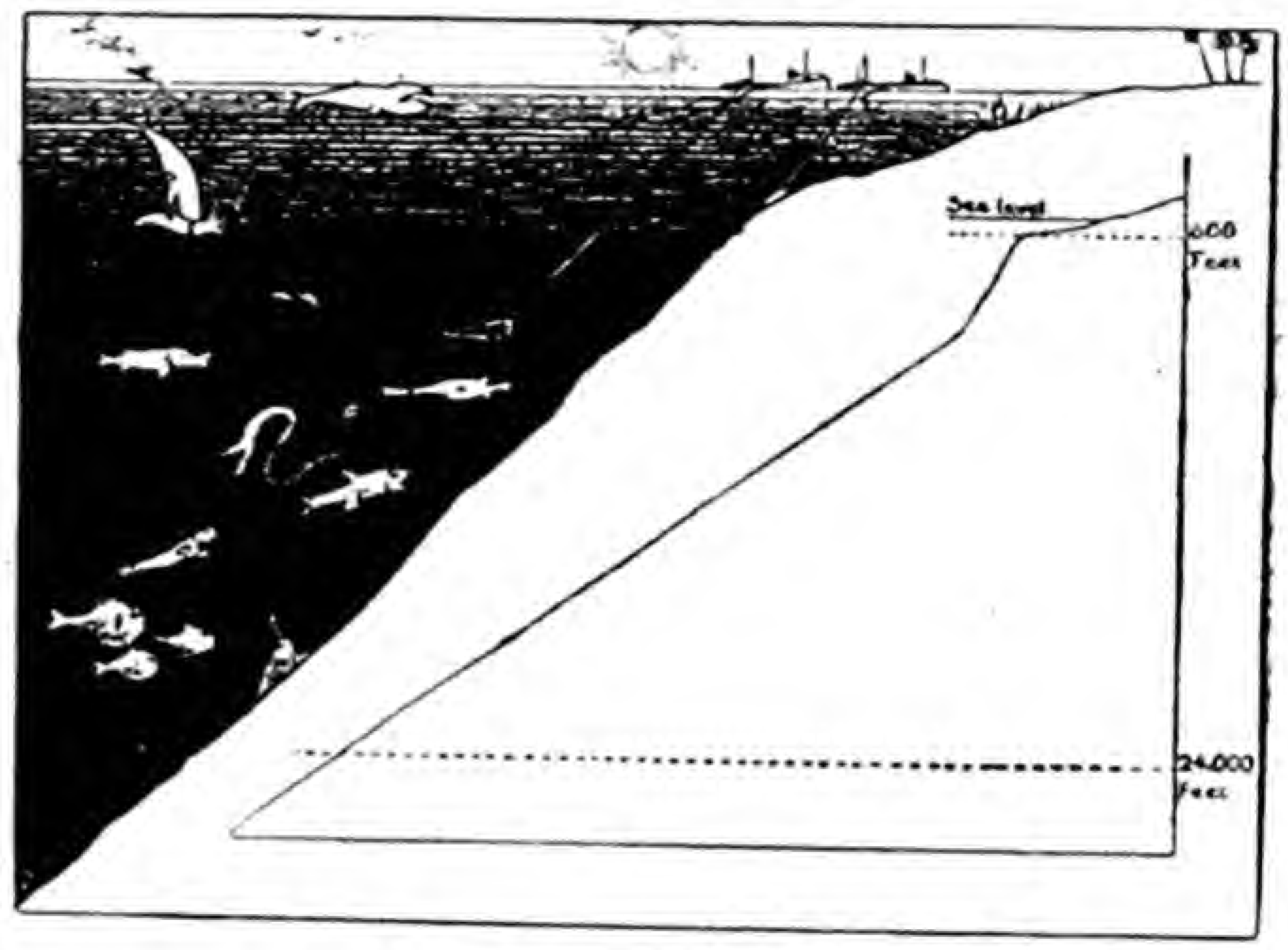


FIG. 120.—*Light only penetrates a short distance down into the sea. All sea-plants and most sea-animals live in the surface layer. Below, there is complete darkness with queer deep-sea animals. Inset, the real depth of the illuminated surface layer* (*about* 600 *feet*) *compared with the rest of the sea. The deepest parts of the sea are over* 6 *miles deep.*

On the other hand, it cannot live just *any-where* in the sea or a lake. It must keep near the surface, because it needs sunlight, and light only penetrates a certain distance into water. Even in the purest water, light strong enough for green plants to use only reaches about 250 feet down: and in most lakes and in the sea near land, where there are always particles of sand or mud, the layer in which green plants can live is thinner—about 50 to 150 feet. So, except

in shallow water, water plants cannot be fixed to the bottom. You can see this clearly enough in the sea: the sea-weeds which grow on rocks make a narrow fringe round the shore: further out to sea they do not grow. (And, by the way, these sea-weeds have no real roots. What look like roots are only "hold-fasts"—arrangements for sticking fast to the rocks. They are not used at all for sucking up any food-materials.) The same is true of lakes. In a shallow lake, pond-weeds will grow everywhere: but in a deep lake, the pond-weeds will only make a fringe round the edge.

FIG. 121.—*Plants that live in the sea need no roots. If they are fixed, like the ribbon-weed (left) or the bladder-wrack (right) they need holdfasts; but these do not suck up water or salts.*

So if green plants are to live far away from the shore, they must float. In quiet water, plants can float on the surface, as duckweed does in ponds. But this will not work where there are waves: you do not find duckweed out in the middle of big lakes. In large bodies of water, the plants that live away from the shore must float *in* the water, not on its surface. To do this easily, they must be very small. The reason for this is a simple one. A plant, unless it is buoyed up by special gas-bladders, as in the common brown sea-weed called bladder-wrack, is just a little heavier than water, and in quite still water would slowly sink. But the resistance of the water prevents its sinking fast; and the greater the resistance, the slower it will sink. Now the weight of the plant, which makes it

sink, depends on its volume—on the total amount of material in it. But the resistance of the water to the plant's sinking depends on the amount of its surface. You can see this easily enough by taking a thin piece of tissue-paper. First see how long it takes to fall to the floor from a height when it is spread out: then crumple it up, and it will fall quicker because, though the weight is the same, there is much less surface on which the air resistance can act.

Now we come to the reason for the smallness of floating water plants. It is that the smaller a thing is, the more surface it has in proportion to its weight or volume, supposing that its shape stays the same. A cube 10 inches each way will contain $10 \times 10 \times 10 = 1{,}000$ cubic inches. Each face of it will have $10 \times 10 = 100$ square inches of surface, and there are six faces, so that its total surface is 600 square inches, which is six-tenths of the volume in cubic inches. But a cube 1 inch each way will contain 1 cubic inch, and its total surface will be 6 square inches, which is six times the volume in cubic inches. So, in proportion to its volume, the surface of the small cube is ten times as big as is the surface of the large cube. The same would be true of two balls, or of any two things of the same shape but different sizes.

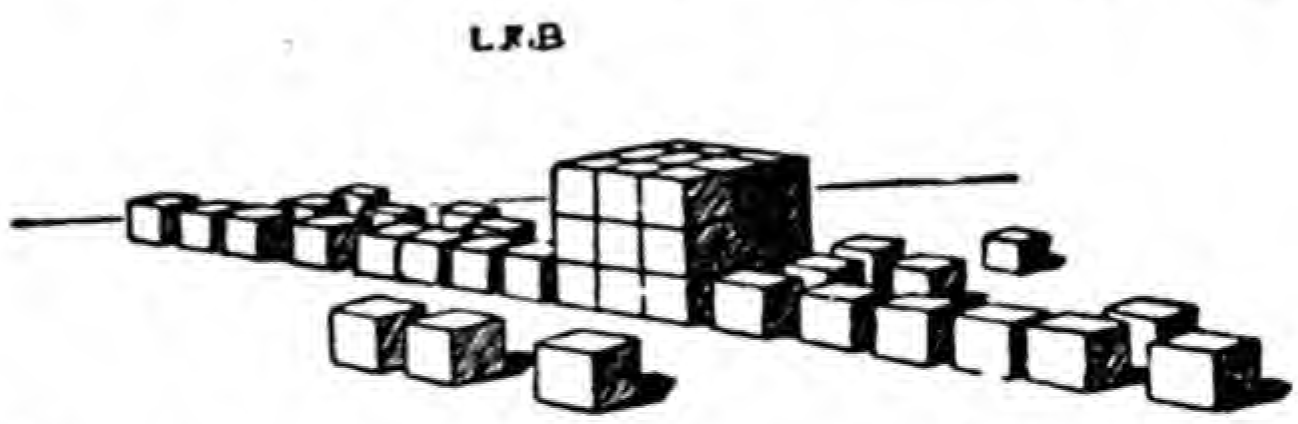


FIG. 122.—*Surfaces and volumes. All the 27 little cubes together have the same volume as the big cube; but they have three times as much surface as it does.*

When we come down to microscopic size, the proportions of surface to volume, and so to weight, get enormous; and plants less than $\frac{1}{100}$th of an inch long have such a big surface in proportion to their weight that they can sink

only exceedingly slowly in still water. Let us think of an example. A very big potato, measuring, say, 5 inches across, would sink quickly if you put it in water. Now imagine the material of the potato divided up into tiny pieces, each the same shape as the original potato, but each $\frac{1}{200}$th of an inch across, which would be a thousand times smaller. You can easily calculate that there would be a thousand million of these miniature potatoes. So each would weigh only a thousand-millionth part of the original potato. But each would have a thousand times as much surface in proportion to its weight as the original potato had, and if you were to put these in water they would take a very long time to settle to the bottom.

Accordingly, we find that the commonest plants of the open water are tiny. The most important of them are of the sort that are called diatoms (see Fig. 113 in Book I); and most of these are less than $\frac{1}{200}$th of an inch long. Also they are usually flat in shape, which gives them more surface than if they were round: and many of them have little bristles which stick out and increase their surface still more. Even in still water they sink very slowly. What with waves and currents, the surface layer of the sea or a lake is never quite still; and though the movements of the water carry some of the diatoms down away from where they can live, they carry others up or keep them from sinking. Diatoms multiply very rapidly, by dividing into two like bacteria and paramecium; and the number which are kept up by the waves and currents and prevented from sinking out of the range of the light is enough to keep the race going successfully.

Thus most green water plants are floating and microscopic, and they have no roots or leaves or stems because they do not need them. Diatoms are the grass of the sea.

They are eaten by tiny animals, and these in their turn by bigger animals like fish. Almost all the life of the sea depends upon the diatom crop.

Water Animals

Then we come to the water animals. We have already spoken of one difference between them and land animals. If they are too big to be able to breathe all over the surface

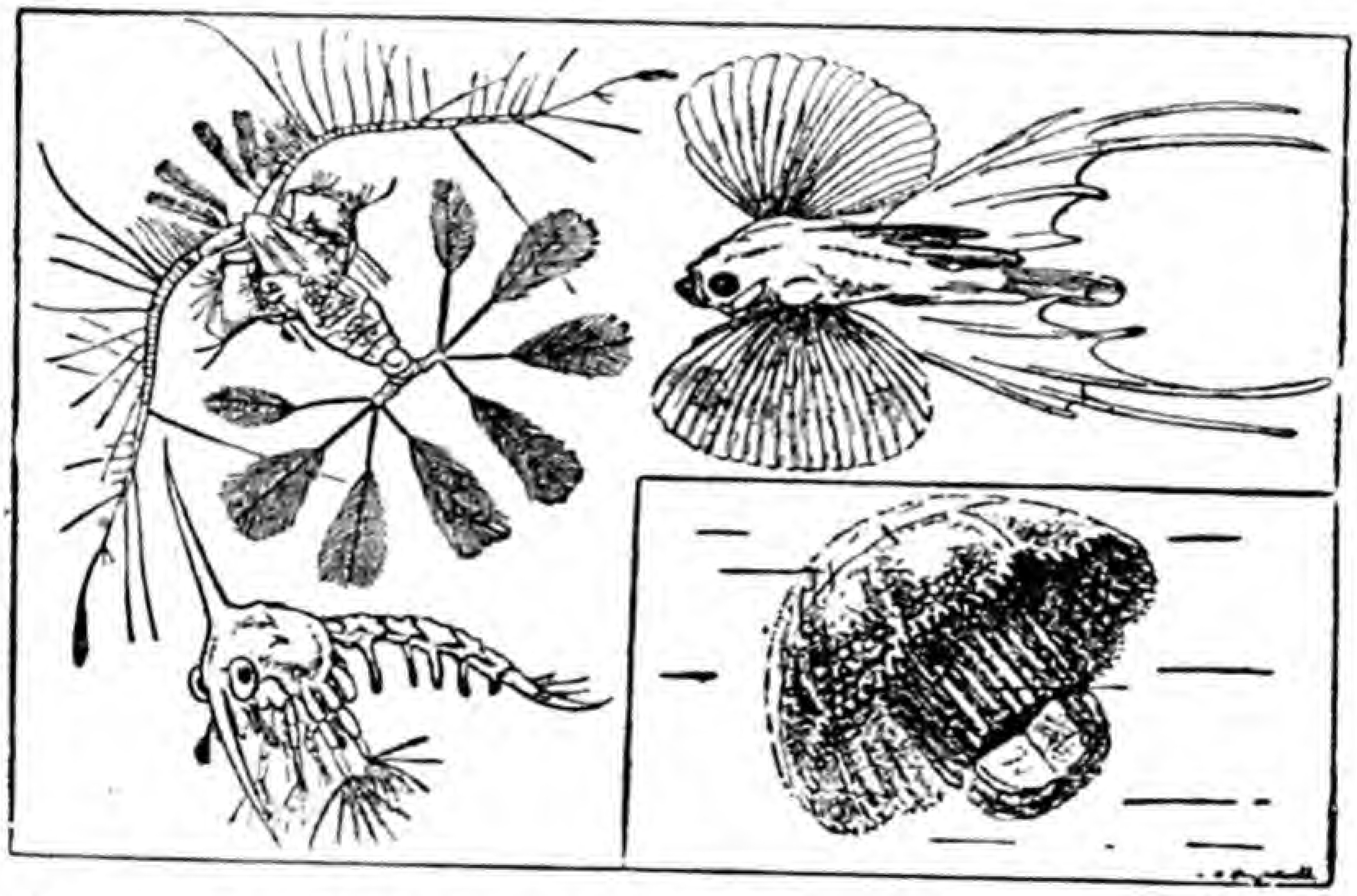


Fig. 123.—*How animals that live in the open water of the sea prevent themselves from sinking. The baby angler-fish (upper right) spreads out fins; the baby crab (lower left) has spines on its head; the little crustacean called Calocalanus (upper left) has feathery bristles; the jelly-fish (inset) keeps making pulsating movements of its bell.*

of their bodies, they need gills to breathe the oxygen dissolved in the water, instead of lungs to breathe the oxygen gas in the air.

Then, just as with plants, water animals have most of their weight supported by the water; and so they do not need such a strong skeleton. Their skeleton serves as an arrangement of levers for their movements, and to help them keep their shape, but very little for support.

Most big water animals are active swimmers, like fish and whales and cuttlefish, which are not real fish, but animals rather like octopuses. These generally have a "stream-lined" shape, like the body of a fast car or an aeroplane. This is designed to make the resistance of the water as low as possible. Air resistance is much less than water resistance; so that land animals do not need to be stream-lined unless they move very fast. It is only in swift flying creatures like birds that air resistance becomes important, and these again have a stream-lined shape. Many small water animals save themselves the trouble of swimming all the time by being very much flattened or by being covered with bristles and so preventing themselves from sinking fast when they are resting; others, like the pearly nautilus, make themselves lighter by means of secreting some gas, and still others by drops of oil, which is lighter than water.

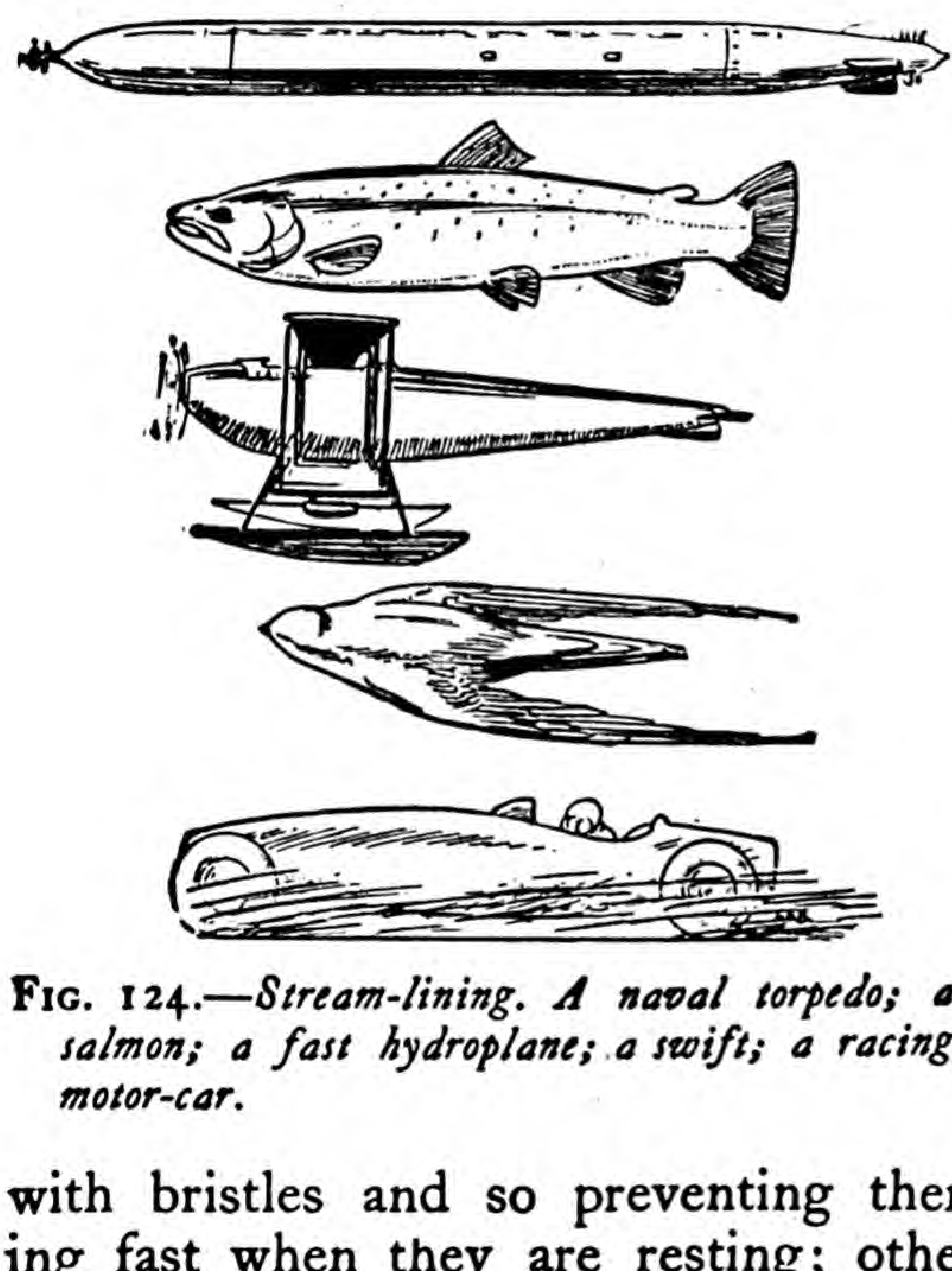


FIG. 124.—*Stream-lining. A naval torpedo; a salmon; a fast hydroplane; a swift; a racing motor-car.*

Many animals of the open sea do not swim in any particular direction: they just keep themselves from sink-

ing. The bell-shaped jelly-fish which flap about like umbrellas opening and shutting are an example. Finally, most of the smallest water animals do not use muscles at all, but keep themselves up by means of the tiny lashing hairs called cilia, which we described in Book I and on page 57 of this Book. None of these arrangements would be any good in a land animal.

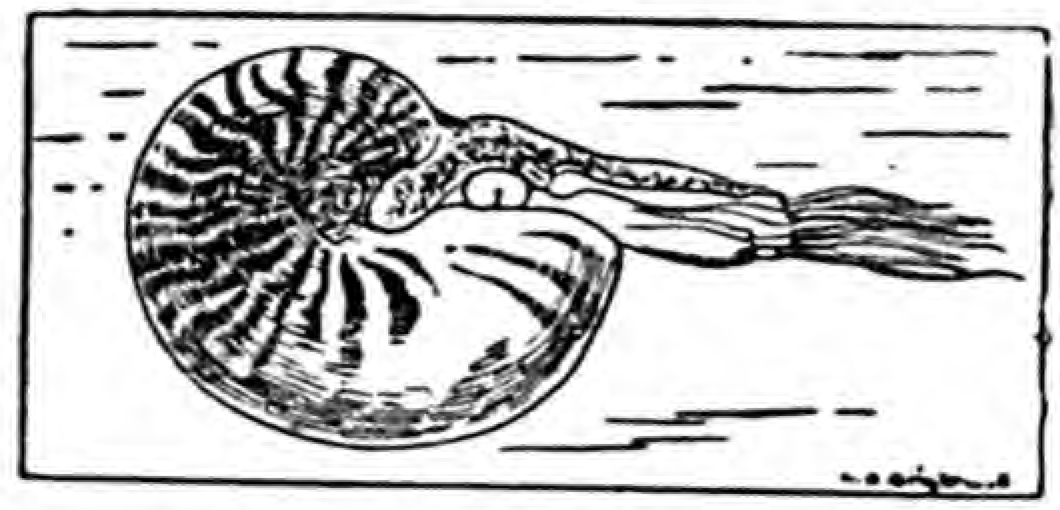


FIG. 125.—*The pearly nautilus has a chambered shell partly filled with gas to keep itself from sinking too fast.*

But what about all the water which is so deep down that it is beyond the reach of sunlight? We know that green plants cannot live in such places, but does this mean that there is no life at all there? The answer is that there is some life, but not very much. Any creatures which live there have to depend for their food on the dead bodies of animals and plants that sink slowly down from the sunlit layer at the surface. There are, of course, bacteria which live on the material in dead creatures and make them decay. But apart from these, all the inhabitants of the deep sea are animals. On the ocean floor there are many creatures of the same general sort as sea-anemones and corals which blindly spread their tentacles in the hope of catching anything which falls on to them; and sponges which make a current through themselves and filter microscopic food particles out of it; and various crab-like and worm-like creatures which scavenge in the mud.

In the layers of water between the bottom and the sunlit surface there are actively-swimming animals, mostly fish, cuttlefish, and shrimp-like creatures. Most of the fish depend on very occasional big meals in the shape of each

other or of dead bodies of large animals; and so to take advantage of whatever may come along, their mouths are often quite enormous, and their stomachs capable of stretching to take in a body bigger than their own. One such meal will often last them for months. Another thing to remember about the deep sea is that it is pitch dark all the time. Accordingly, many of the fish and cuttlefish that live there are nearly or quite blind, and rely on smell

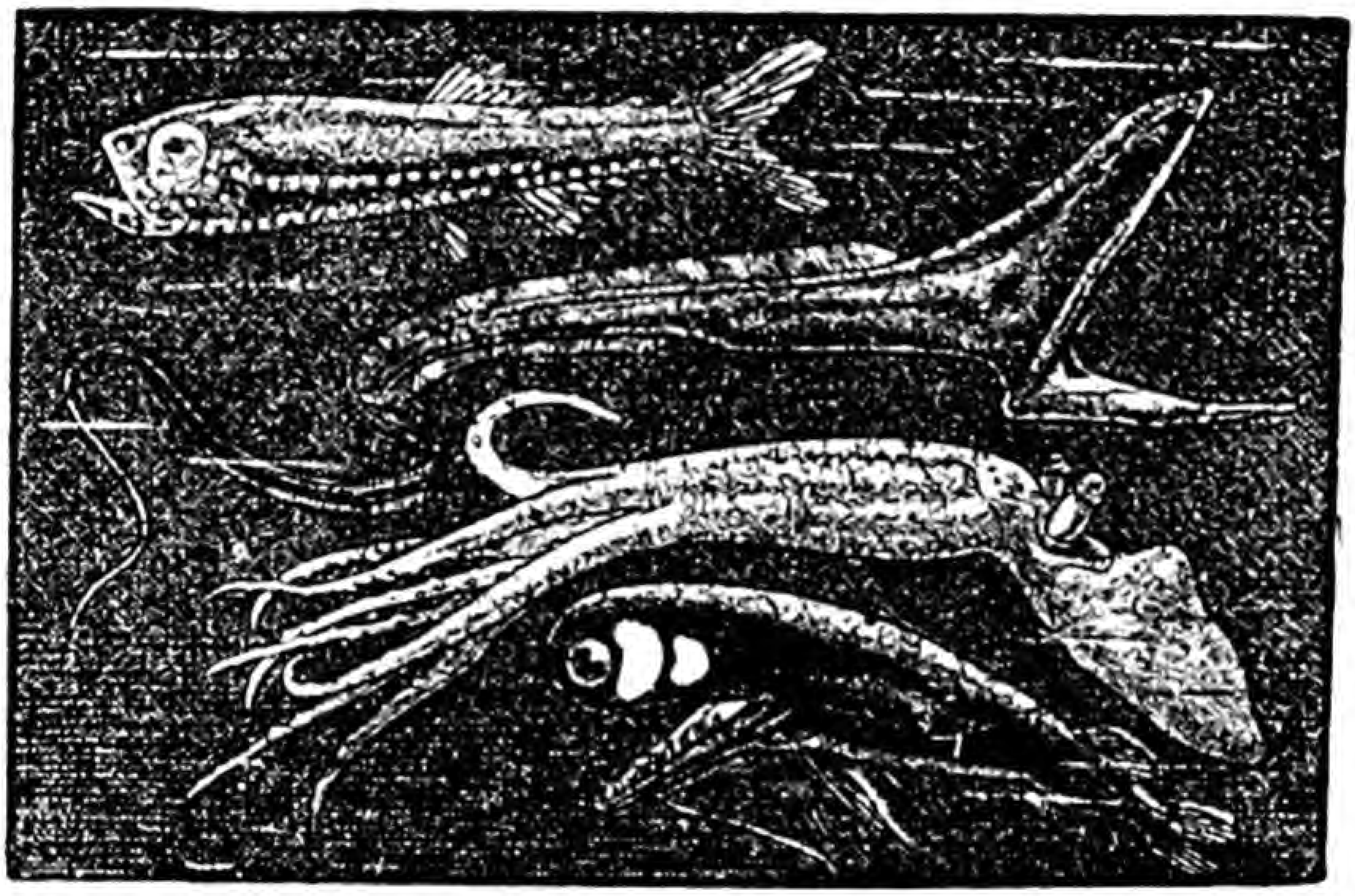


FIG. 126.—*Some inhabitants of the deep sea. Above, a fish with a huge eye and rows of luminous organs, looking like portholes on a steamer at night. Next, an almost blind fish which can swallow prey bigger than itself. Next, a cuttlefish with eyes on stalks. Below, a fish with big mouth and eyes and luminous organs acting as headlights.*

and touch to find their food and their mates. But others have gone to the opposite extreme. Like cars at night, they make their own light. They have phosphorescent organs on their bodies which shine in the dark, and their eyes are enormous, to catch the least glimmer from the lights of other animals in the distance.

There is another thing about the deep sea. The con-

ditions are always the same. There is no day and no night because light does not penetrate there. And there are no seasons: when summer sun warms the surface of the sea, the heated water stays at the top because it is lighter. The cold water sinks to the bottom, and there is nothing to heat it up. The really deep sea is very cold, only a few degrees above freezing-point; and it stays at almost the same temperature all the year round. For the same reason, there is hardly any difference between different regions of the deep sea. The living conditions are about the same deep down in the Arctic Ocean as they are deep down below the equator; the only difference is in the food which sinks down, and this will be different according to the creatures which live and die in the surface layers.

On land, however, and in shallow water, conditions are not so uniform. Here climate makes a great deal of difference to the way in which animals and plants shall live. Conditions in the arctic are quite different from conditions in the sandy desert belt or in the tropical forest.

You will not be able to visit the places for yourselves; but from pictures and visits to museums and zoos and botanical gardens you can understand a great deal about them and the life that grows there. Also, even in England, you can study for yourselves many of the ways in which animals and plants fit themselves to their surroundings. We have no deserts, but some soils are very dry, and the plants there are very different from marsh or woodland plants. We have no tundras as in the arctic, but the moors on our hills and mountains resemble tundras in certain ways. We have fir woods and woods of broad-leaved trees, grassland and ploughland. Great Britain, in fact, is a very varied country, and it is possible to find many different kinds of surroundings in it for life to inhabit.

Different Kinds of Surroundings in your own Country

We will take a few examples. Think of a sandy common, a pond with a marsh at one end, a stretch of open downland, and a wood. The animals and plants that live in them will be very different. On the downland you will see hares, but you will not find them in the other places: their long hind legs are made to run fast, but they must have open country for their running. Rabbits, on the other hand, which make burrows, are not confined to open country. They do not need to run so far or so fast, and have shorter legs; but they never feel safe far from their burrows. Among insects, the grasshoppers of various kinds are very common. Their long hind legs are suited for jumping in dry, open country, but would be out of place in a tangle of tall herbage in a wet marsh.

Fig. 127.—*Downland animals and plants. Hare, partridge, skylark, chalk-hill blue, grasshopper, grasses, daisy, thyme, milkwort, bird's-foot trefoil.*

On the down, with its short turf, you will see flowers like daisies and eyebright and thyme and milkwort. They are all small plants, and would never do well where taller, juicier plants could grow, as in a hedgerow with its cow-parsley and jack-in-the-hedge and campion. There they

would never be able to reach up to the light, and would die. A daisy is beautifully suited to its surroundings. You look at its little rosette of flat leaves, and you think how pretty it is. However, it is not made to look pretty to you, but to be useful to the daisy. The daisy leaves grow out and flatten down the grass and other small plants so that they cannot get any light or air, and die, leaving the daisy to grow. Even the daisy shows the struggle for life. On the open down, you will get no creepers such as ivy or bryony or honeysuckle: these need trees or shrubs on which to climb.

FIG. 128.—*Woodland animals and plants. Oaks, elms, ivy, primrose, bluebell, red squirrel, spotted woodpecker, rabbit.*

In the wood, the trees cut off so much of the light that only a few plants can grow under them; and they are mostly shade-loving kinds, which would not thrive out in the open. There are some kinds which need a good deal of light; these have to make haste and get their growing and flowering done before the trees come into leaf. That is why the chief blossoming-time in the woodlands is in early spring, with the primroses and windflowers and bluebells, while by July, when the fields are brightest, there is hardly a flower in the wood under the trees.

Just as you would not expect to find hares in a wood, so you would not expect to find squirrels or woodpeckers

out on the open down: they are suited to tree life. The squirrel's lovely bushy tail is to help him in balancing as he jumps from tree to tree. The woodpecker's tail is made of pointed, very stiff feathers, which prop him up as he holds on to a tree-trunk; and his beak is made wonderfully strong, so that with it he can chisel the wood to find grubs, or to make his nesting-hole, which may be a foot in depth.

FIG. 129.—*Life at the edge of a pond. Try to see the way in which each kind of plant or animal in the picture is suited to the particular place in which it is found.*

The heathy common will be drier than the woodland; if it were not sandy and dry, broad-leaved trees like oaks or beeches would be able to grow on it. As it is, the trees that thrive best are firs; as we shall see later in this chapter, their needle-like leaves fit them to live in dry places, because they let very little water vapour escape. Gorse is another typical plant of such places; and it, too, instead of big flat leaves, has mere prickles. You would never find

gorse in a wood or a marsh, any more than you would find there the common brown lizard, which also inhabits sandy heaths.

In the pond with its marshy end, you will find an altogether different set of animals and plants. The water-weeds trail about because they have no strong supporting skeleton, and their leaves are made so as to be able to use the carbon dioxide dissolved in the water. Water-lilies, on the other hand, cannot do this so well: they send up their leaves to the top of the water, and spread them out there in the air. Their flowers, too, depend on insects for their pollination, and must keep their pollen dry. So they are shut up in water-tight buds and only unfold when they reach the surface. Both leaves and flowers are moored to the stem and roots, which are in the mud at the bottom, by long flexible stalks very like cables. Nearer the edge are plants like bulrushes and sedges, which root in shallow water, and send up most of themselves into the air.

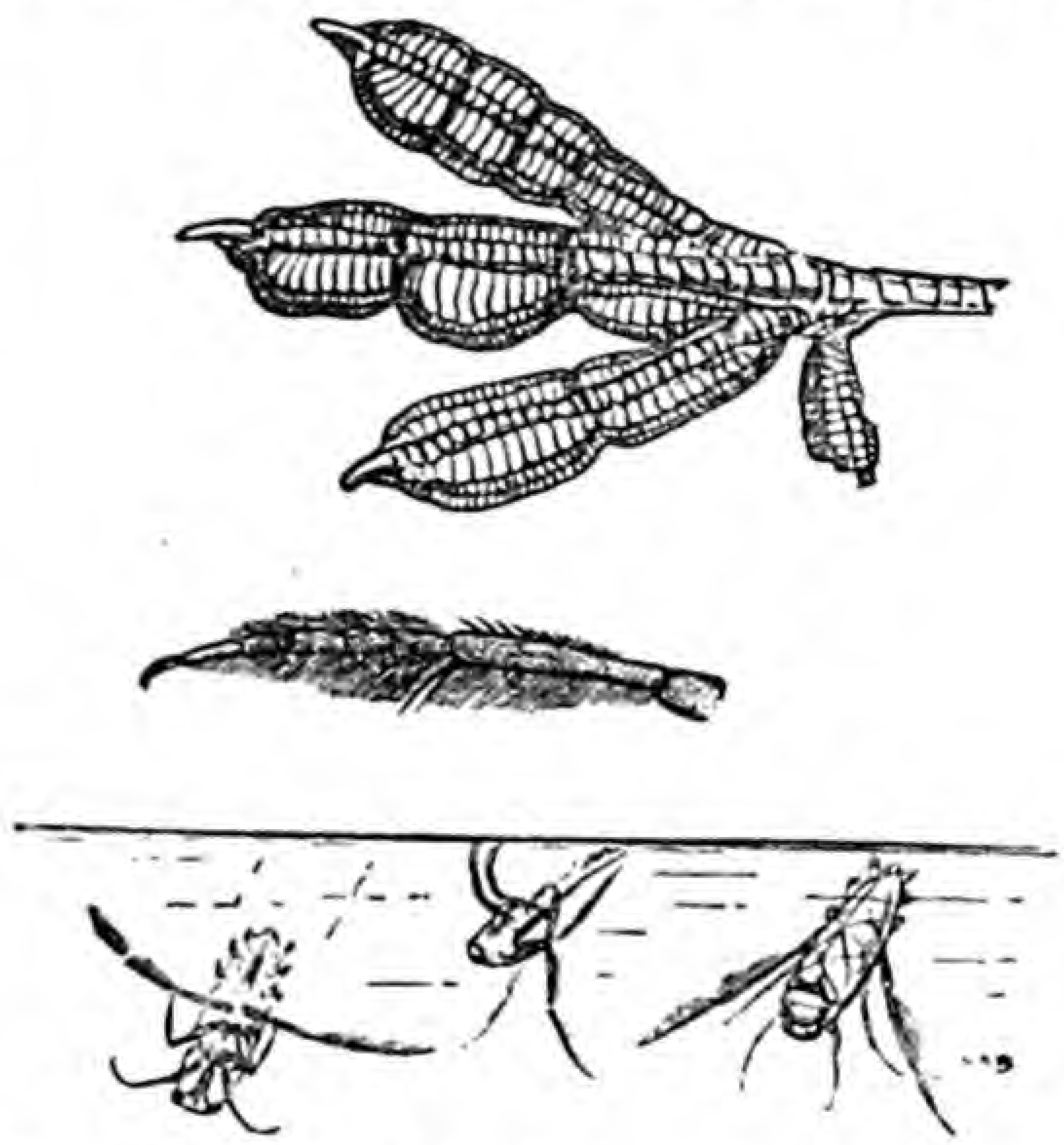


FIG. 130.—*Limbs suited to water life. Above, the foot of a moor-hen, with lobes of webbing. Centre, the swimming leg of a water-beetle (Dytiscus), fringed with strong hairs. Below, water-boatmen.*

Among the animals of the pond, the wading birds like herons are rather like the bulrushes among the plants: they cannot swim, but use their long legs to wade out into the water, where they spear fish with their sharp beaks. The swimming birds, like moorhens or ducks, are more

like the water-lilies. They can live on the water, but not in it. They are specially suited for swimming by having webs on their feet, either stretched between the toes as in ducks, or making a separate fringe round each toe, as in moorhens and grebes. Finally, the fish are like the water-weeds, in being suited to under-water life.

The water insects, too, are very different from the land insects. The Water Boatmen have one pair of legs turned into powerful oars with which they row themselves along; for some curious reason, they prefer to swim on their backs. The big water-beetles, called Dytiscus, also row themselves through the water; you will find it interesting to look at their rowing legs and see how they are expanded like the blades of an oar, and fringed with stiff hairs which act much as does the web along the moorhen's toes. Many insects spend the early part of their lives, corresponding to the caterpillar stage of the butterfly, in the water, and only come out on land when they grow wings. Dragonflies and mayflies and gnats and mosquitoes are examples.

Many of these, as we saw in Chapter I, have gills to breathe by under water. Others, however, breathe by air-tubes, like land insects, and have to come up to the surface to take in air at regular intervals. If you look at a mosquito grub (wigglers, people often call them, from the way they move) you will see that it has a pointed arrangement at the hind end of its body. This consists of a series of flaps which cover the opening to its air-tubes, and shut up tightly into the shape of a cone so as to keep the water out. When it wants to breathe, it comes up to the top of the water, pokes the cone out, and opens the flaps. These flaps fold out into a star, and lie on the surface skin of the water, which we spoke of in the first chapter of Book I. The surface skin of the water is strong enough to support the

wiggler as it hangs head downwards in the water, and quietly takes in air through the hole in the middle of the star.

In parts of the world where the diseases called malaria and yellow fever exist, mosquitoes are dangerous, because they spread the diseases by biting people, as Sir Ronald

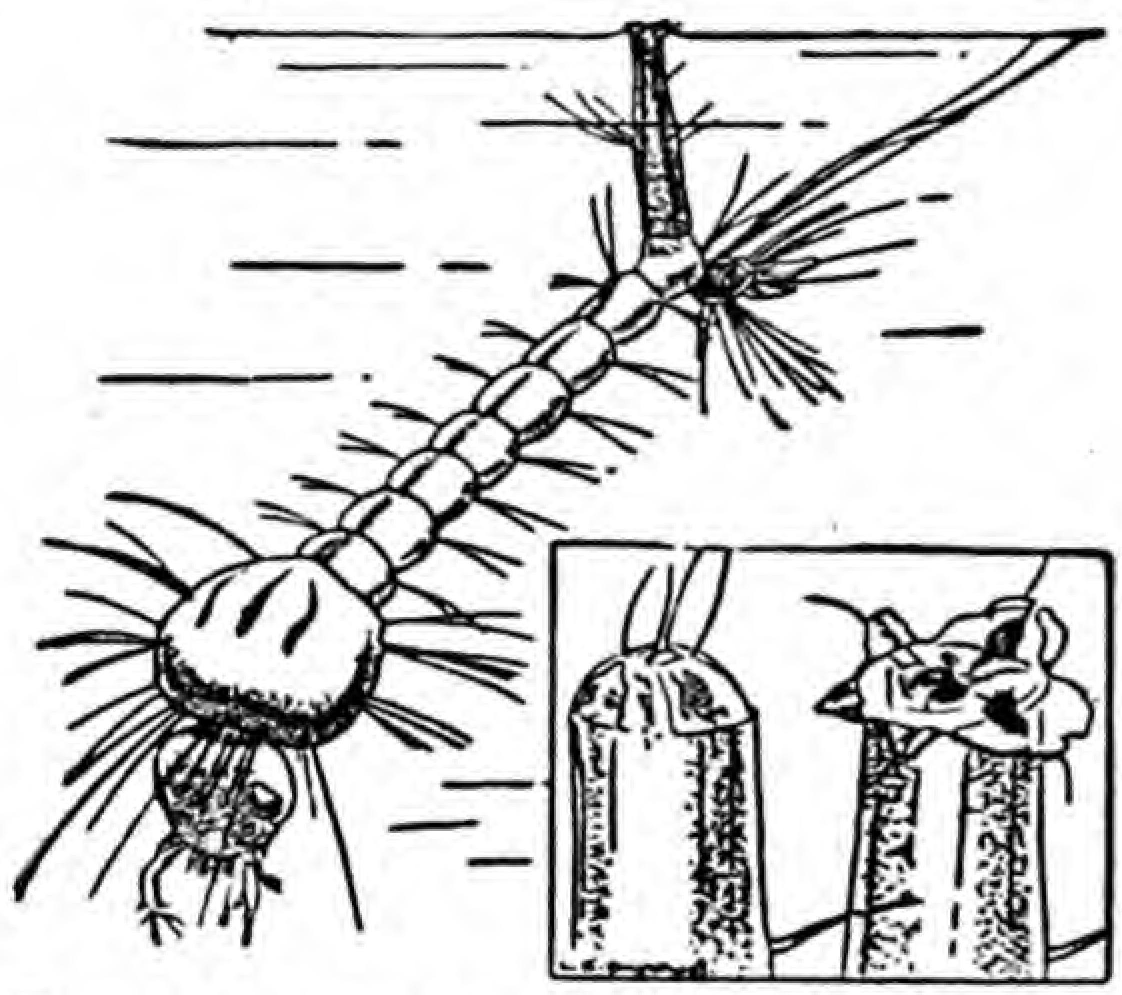


FIG. 131.—*A mosquito grub sticking its breathing-tube through the surface film into the air. Inset, the end of the breathing-tube more highly magnified. On the left, shut; on the right, open, showing the openings of the two air-tubes.*

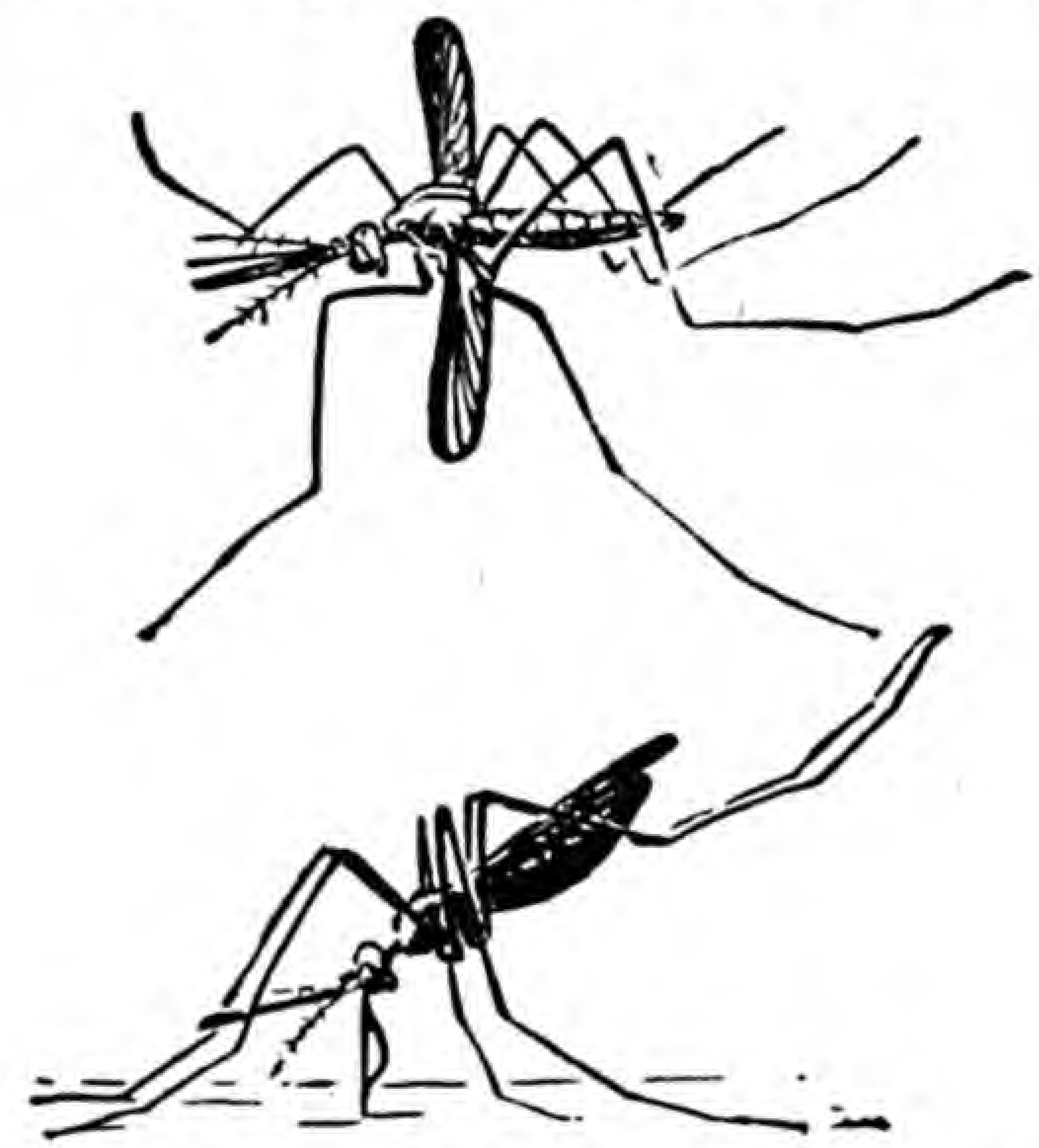


FIG. 132.—*Above, a female mosquito of the kind which spreads malaria. This is drawn from a model, very much enlarged, which is in the Natural History Museum at South Kensington. Below, a mosquito of the same kind biting a man. Her abdomen is swollen with the blood that she has sucked up.*

Ross discovered. The female mosquito needs blood to ripen her eggs; she settles on a man's skin, drills a tiny hole through it with the sharp tip of her proboscis, and then sucks up his blood. If he has any malaria germs in his blood, some of these get into the mosquito and develop and multiply there; and if she bites a healthy man later,

some of the germs will pass into his blood and give him malaria. One way of getting rid of mosquitoes is by putting oil on the pools where their grubs live. The oil spreads out in a film over the surface of the water, and prevents the wigglers getting air into their breathing-tubes, so that they suffocate.

In the marsh near the pond, you will find frogs. They are only suited to live in damp surroundings, because their skin is thin and moist and would dry up in dry places. You would not expect to find frogs out on the down, or on the sandy heaths where the lizards are at home.

So we see that even in one kind of climate there are many different kinds of surroundings, according to the kind of soil, whether the country is flat or hilly, and whether it is wet or dry, and that the animals and plants are suited to their surroundings.

There are plenty of other kinds of surroundings to be found in a country like England. There are flowing rivers and streams, sand-dunes, rocky hillsides, rich water-meadows, mountain moors, and peat-bogs; there are the special surroundings made by man with his buildings, with special animals suited to them like house-mice and rats, and sparrows and swallows and house-crickets; there are all the different kinds of sea-shore, sandy stretches and rock-pools, mud-flats and shingle beaches. It will be interesting to you to study as many different kinds of surroundings as you can, and try to discover how the animals and plants that you find there are suited to the places where they live. This will suggest to you many little problems which you can think over. The question of adaptation, as it is called, is one of the most interesting of all the problems of the science of living things, and in a later book we shall have more to say about it.

QUESTIONS AND EXERCISES

CHAPTER I

1. What gas did Priestley discover? How can you show how much of it there is in ordinary air?

2. Write down five facts about breathing.

3. Why might it be unsafe to go down into an old well, and how could you find out if it were?

4. Why do people put a sheet of paper over the fireplace to make the fire burn better?

5. What is the difference between the air we breathe out of our lungs and the air we breathe in?

6. Give examples of processes of (*a*) "burning" with no flame and very little heat, (*b*) burning which is so rapid that an explosion results.

7. How can you collect water from "breath"?

8. When magnesium ribbon is burnt, it turns to ash. Does the ash weigh more or less than the magnesium before burning?

9. Which of the following changes are "chemical" and which "physical": iron rusting, water turning into steam, water turning into ice, magnesium ribbon burning, a wet hayrick steaming? Which of these use energy and which give out energy?

10. Give some interesting facts which depend upon the fact that "the higher we go the thinner the air is."

11. Name animals which breathe (*a*) through holes in the surfaces of their bodies, (*b*) through their skins, (*c*) through gills. Why does a fish die out of water?

12. How can you show that plants breathe?

13. What are the chief kinds of waste material produced by the slow combustion in your body, and how are they got rid of?

14. What are the main uses to you of the energy produced by the slow combustion in your body?

CHAPTER II

1. What is a muscle? Explain what a muscle does when it contracts.

2. Describe what happens in your body when you bend your arm at the elbow. What muscle straightens the arm again?

3. Write a short account of tendons and describe how they work.

4. What do we mean by the mechanical advantage of a lever? Compare the leverage when your biceps contracts with that when you use a crowbar.

5. Explain how your foot acts as a lever.

6. Where is your diaphragm, and what does it do?

7. How does an earthworm crawl?

8. Where are cilia to be found in our bodies, and what do they do?

9. What do you mean by *recoil*? Give three examples of recoil action.

10. Name some animals and plants which get "free transport."

CHAPTER III

1. In what ways can the nervous system be compared to a telephone exchange? What are the nerves called which take a message outwards? What organs receive this message, and how do they act when they get the message?

2. How many different senses have you got? Give a list of them.

3. Name the parts of your eye which correspond to the following parts of a camera: film, lens, iris diaphragm and aperture; and explain how, in focussing, a camera works in one way and your eye in another.

4. What do we mean by short sight? What kind of lenses do we need in spectacles to correct short sight? Give reasons for your answer.

5. Explain how a stereoscope is made, and why it is that it can make pictures look solid.

6. Why is it that after you have been in a darkened room for some time you begin to be able to see a little? Will there be any difference in the appearance of the objects in the room?

7. How would you find out which parts of your body are sensitive to (1) touch, (2) heat or cold, (3) pain? Why is the result of over-eating painful?

8. What is an anæsthetic? Name two anæsthetics and say when they are used.

9. How do you know, when your eyes are shut, in what position you are holding your limbs?

10. Explain why turning rapidly round makes you giddy.

CHAPTER IV

1. What is the difference between cold-blooded and warm-blooded animals? Give two examples of each. Describe an experiment which shows that bodily activity depends upon temperature.

2. Why must cold-blooded animals hibernate to live through the winter? Make out a list of animals which may be seen out of doors in the summer but which are not seen in the winter. Give reasons in each case for their absence in the winter.

3. What is the normal temperature of your body? Explain clearly the difference between temperature and heat.

4. Name a few of the things where a careful measurement of the temperature is of the greatest importance. Choose two of these and try to find out from a children's encyclopædia why this careful measurement is so important.

5. Explain how a thermometer works.

6. What is the difference between the Centigrade and the Fahrenheit scales of temperature? A healthy room temperature is about 60° F. What is this on the Centigrade scale?

7. Give reasons for the following: (1) Why we use a wooden spoon to stir cooking porridge. (2) Why polar explorers never touch metal with their bare hands. (3) Why the hand is untrustworthy to see whether the baby's bath water is at the right temperature.

8. Give one example each of convection, conduction, and radiation of heat. Why is radiation very important to us?

9. Explain how a Davy Lamp makes for safety in mines.

10. What effect does a moist climate have upon the temperature at the surface of the earth?

11. A thermos flask keeps hot things hot and cold things cold. Explain how this is possible.

12. Explain how dew is formed. Is there likely to be more dew after a clear night or a cloudy night?

13. In hot countries people often keep drinking-water in porous earthenware jars. Why is this?

14. How could you find out if heat was given out or taken up when steam condenses to water?

15. Give reasons: (1) Why the climbers on the Mount Everest Expedition could not boil an egg. (2) Why a small piece of ice cools a large glass of lemonade. (3) Why alcohol is used occasionally in thermometers.

CHAPTER V

1. What is the use of shivering when you are cold?

2. Why do birds fluff out their feathers in cold weather?

3. What arrangements are there for controlling temperature in the school heating apparatus? How is the temperature of a beehive regulated?

4. Why do we feel hotter on a muggy day than on a dry day, even when the temperature of the air is the same?

5. What do you mean by ventilation? What arrangements are there for ventilation (1) in your schoolroom, (2) in your bedroom, (3) in a cinema?

6. Most people are healthier if they do not wear too many clothes. Why is this?

7. Why is sunshine very important to health?

8. Why do the natives of tropical countries have dark skins?

9. What are carbohydrates and proteins, and what are they used for in the body? Name foods which contain a good deal of these.

10. What is meant by the phrase *a balanced diet*?

11. Why is it important to get "food-rubbish" out of the body? What foods help this removal?

12. In what ways do games train us?

13. Give two examples of insects which spread disease. What is the special danger of the house-fly?

CHAPTER VI

1. Where does water enter a plant, and where does it pass out of the plant? Describe the experiments in support of your answer.

2. Describe experiments showing how roots are guided in their growth.

3. A green plant grown in the dark will die. Explain why this is so.

4. What are the raw materials of plant food?

5. Describe an experiment to show that plants need oxygen for breathing.

6. Give three examples of movement in plants. What use are the movements to the plant?

7. Why has a plant no stomach?

8. What is the use of pollen?

9. Give two examples each of wind-pollinated and insect-pollinated flowers, and explain why they look so different.

10. What is the difference between a *seed* and a *fruit* in botany?

11. Give examples of three different ways in which seeds are dispersed.

12. From what plants can the following useful substances be derived: soap, ebonite, rope, newsprint, linen?

CHAPTER VII

1. What are the chief differences between land and water plants?

2. What are the chief kinds of plants found in the sea, and in which parts of the sea do they grow?

3. Give examples of different ways in which plants and animals of the open sea are prevented from sinking rapidly.

4. Why is it that diatoms are so very important in maintaining life in the sea? Make a diagram showing the way in which the food made by diatoms eventually becomes available to man.

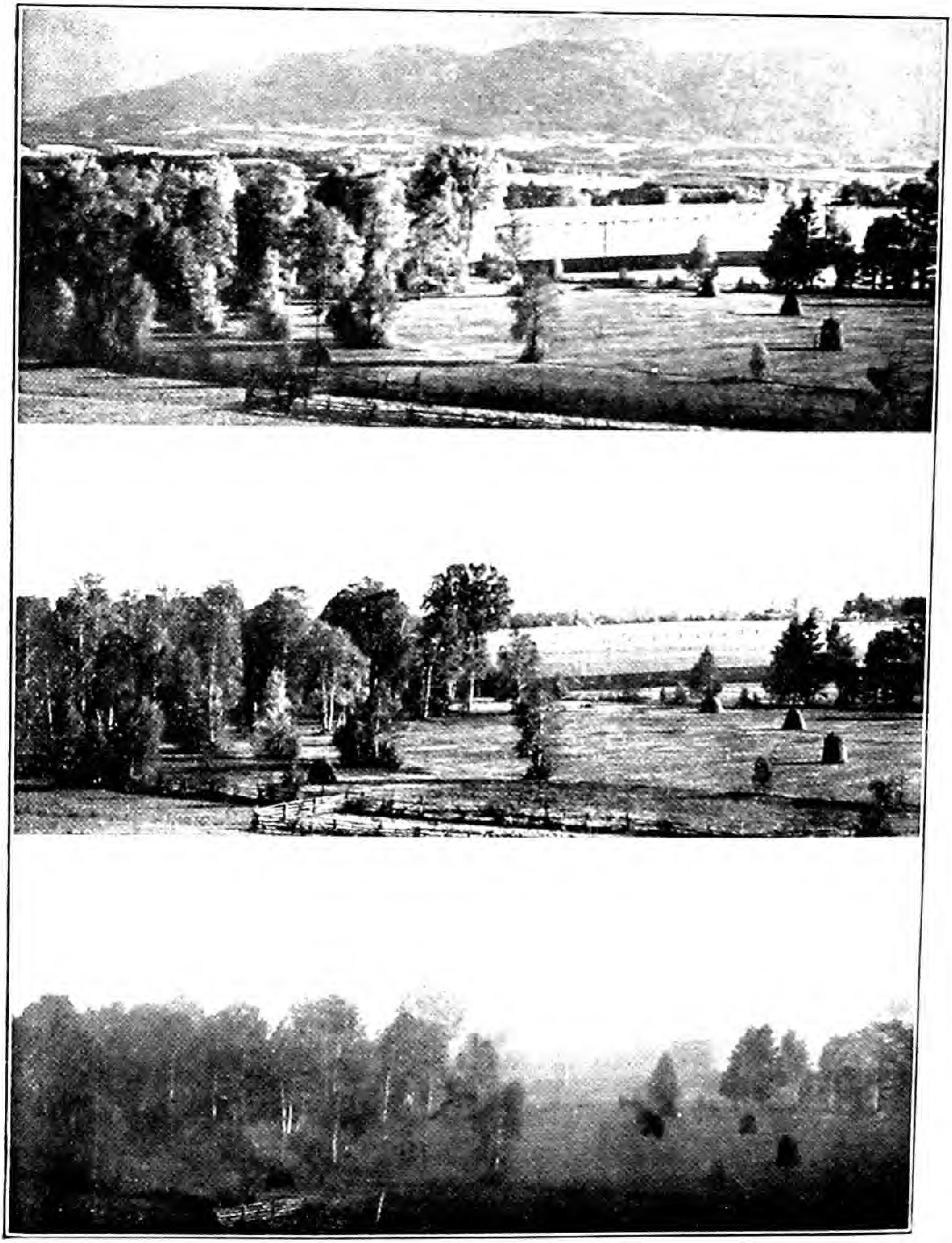
5. What is meant by a *stream-lined* shape? Name both animals and machines which are *stream-lined*.

6. What are the chief characteristics of life in the deep sea?

7. Give examples of characteristic animals and plants from each of the following surroundings: a wood, a pond, a chalk down; and explain how they are fitted to their surroundings.

INDEX

PRINTED IN GREAT BRITAIN BY
BILLING AND SONS LTD., GUILDFORD AND ESHER
G1009



[*Photographs by courtesy of Professor von Angerer.*

Reading from the top, the same scene photographed by infra-red light, ordinary light, and ultra-violet light. (*See pages* 152, 153.)

AN INTRODUCTION TO SCIENCE
BOOK III

Forces at Work

By E. N. DA C. ANDRADE, D.Sc., Ph.D., F.R.S.
Quain Professor of Physics in the University of London

and JULIAN HUXLEY, M.A., F.R.S.

With Drawings by COMERFORD WATSON

BASIL BLACKWELL · OXFORD

First printed, August 1934
Reprinted, April 1935
Reprinted, February 1939
Reprinted, January 1942
Reprinted, September 1943
Reprinted, February 1945
Reprinted, July 1946
Reprinted July, 1947
Reprinted September, 1949

Printed in Great Britain

CONTENTS

CHAPTER VI

CHAPTER VII

CHAPTER I

THE WORLD OF ELECTRICITY

Electricity in the Service of Man—Electricity in Nature—Animal Electricity — Frictional Electricity: Conductors and Insulators — Electrical Attractions—Electrical Instruments

Electricity in the Service of Man

ELECTRICITY is a form of energy which man has turned to his service in hundreds of ways. Anybody who lives in a town is reminded of this on every side. In the streets we see trams of which the wheels are turned by electricity, and motor buses in which the petrol vapour, mixed with air, is fired by an electric spark. At night the streets are lit by electric lamps of many different kinds, and advertising signs, made of long tubes bent into many shapes and filled with a soft red glow, show us yet another kind of electric light. Here and there great buildings, called generating stations, with tall chimneys, which tower above the surrounding houses, remind us that electricity is, as we read in Book I, made by steam engines which need the heat of great furnaces to drive them. In winter we see, in many rooms, radiators, made of wires which are kept red hot by electricity and heat the air: in summer, fans, turned by electricity, make a pleasant draught. In one house we may find a sewing machine driven by electricity, in another a vacuum cleaner run by the same agent. In fact, wherever light or heat is wanted, or wherever there is a wheel or handle to be kept turning, we are likely to find electricity at work.

For every electrical servant that we come across by chance in this way, however, there are many working for us that we shall not find unless we look for them. Into whatever factory we go we are likely to find many, if not all, of the machines run by electricity. Besides this, however, there is quite a different use of electricity in industry,

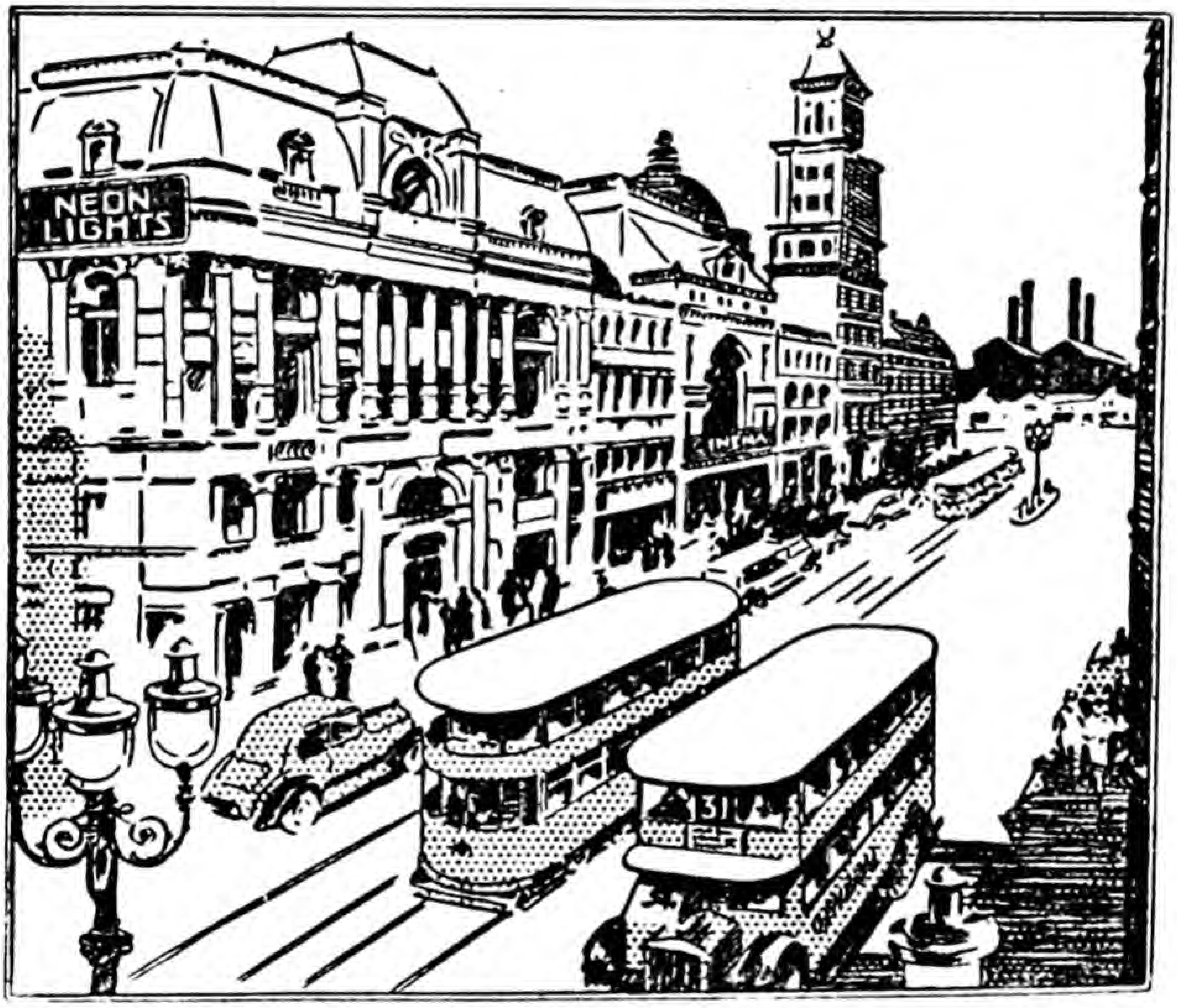


FIG. 1.—*Uses of electricity in everyday life. In the background is a generating station.*

which we may call a chemical use. In Book I we saw how electricity could be used to break up water into the two gases, oxygen and hydrogen. This is a particularly simple example of the chemical changes that can be produced by an electric current. Nearly all plating, that is, the putting of a thin coat of one metal over another to protect it or to make it look better, is done by electricity. Silver-

plated teaspoons (which are often called electro-plated, reminding us that they have been produced by electricity), nickel-plated bicycle fittings, chromium-plated buttons and door knobs, serve to remind us of this use of electricity, of which something more is said in the next chapter.

The chemical effects of electricity are used in many other ways—for instance, in separating out metals from the compounds which are found in nature. Although one or two metals, such as gold, are found occasionally as lumps or grains of pure metal, all bright and ready for use, most of them are joined to other things and occur as chemical compounds, often as rocks or earths which you would not suspect to be made up of bright metals and gases, or bright metals and sulphur, as they actually are. Aluminium, for instance, never occurs in nature as a metal, but all clay contains large quantities of aluminium combined with oxygen. All the aluminium which you see as saucepans and such-like is made from a special kind of clay called bauxite, and the separation of the metal is entirely done by electricity. The picture shows the great pipes that lead water to the water turbines that turn the dynamos to generate the electricity to make aluminium from bauxite at Kinlochleven in Scotland. The chemical effects of electricity are, then, exceedingly important.

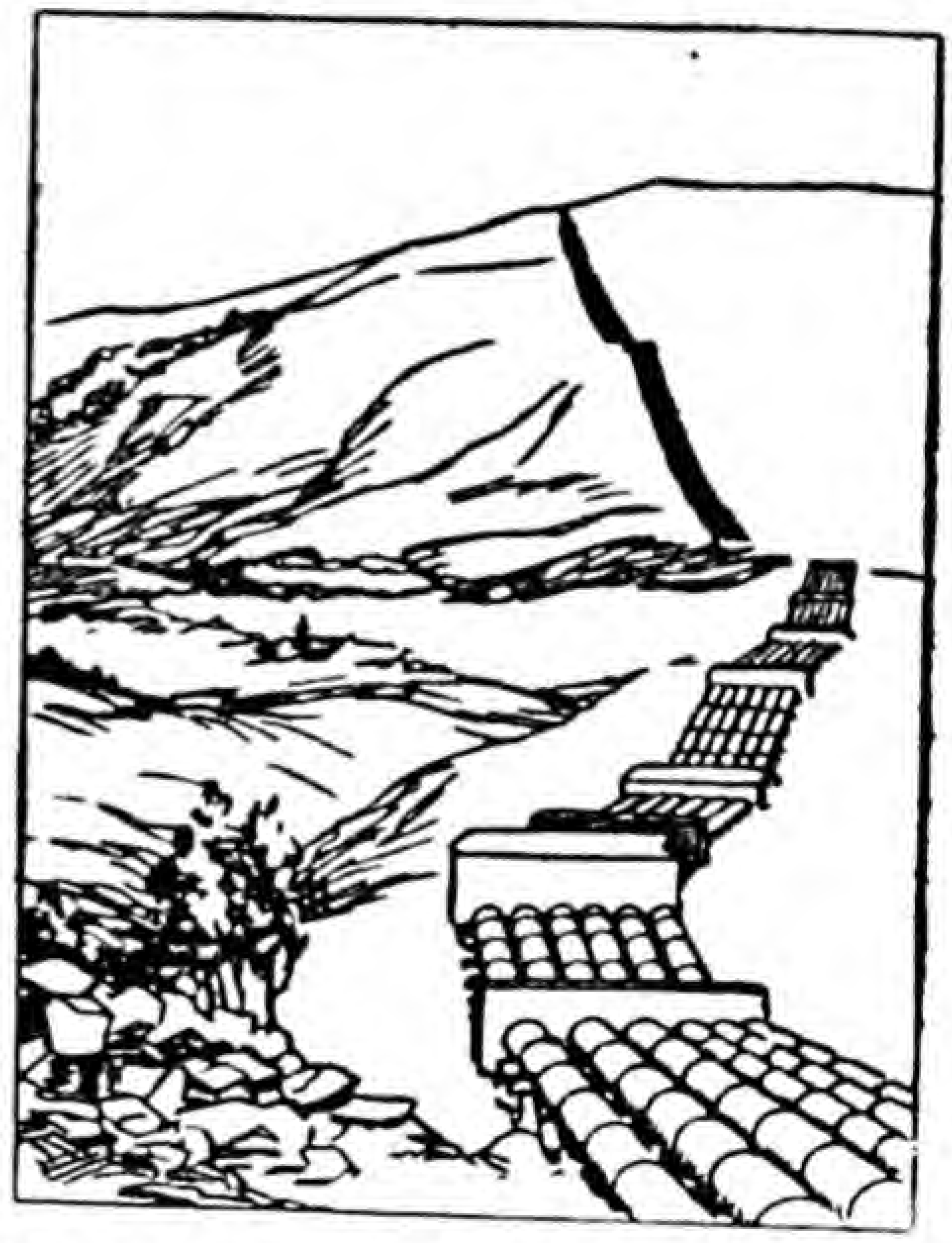


FIG. 2.—*The pipes that bring the water to the water turbines that produce the electricity to make aluminium at Kinlochleven.*

We shall see later that an electric current can be used to make iron magnetic, and the magnetic crane, described on p. 62 of Book I, is an example of the industrial use of this property of electricity.

In factories the heating effect of electricity, used in houses for small electric "fires" or, as they are better called, radiators, is often very valuable. Electric furnaces of various kinds are used for melting metals and for many other purposes.

If two pieces of carbon, or of metal, joined to wires from a supply of electric current, are made to touch for an instant and are then separated by about half an inch or so, an intensely bright flame, which is called the electric arc, burns steadily between them. Formerly it was much used for lighting, but nowadays it is largely replaced by other kinds of electric lamps. Besides being bright, the electric arc is also extremely hot, and is used in special electric furnaces. Further, it has the property that the heating takes place in a very small space round the arc, and advantage can be taken of this in engineering. For instance, if a sheet of metal is connected to one wire of an electric supply, and the other wire is connected to a rod of carbon, then if the carbon is brought up close an electric arc will burn between it and the metal. The heat near the point of the carbon is so great that the metal melts, and, by drawing the carbon along, the metal sheet can be cut in two, as by a knife.

Two bars of metal lying end to end may be fused together by an electric arc between them and the carbon, extra metal being melted into the join if necessary. This kind of process is called electric welding, welding being the name given to the joining of pieces of metal by softening them by heat, or melting them together; a joint

made in this way is called a weld. In another method of electric arc welding both pieces of metal are, as in the process just mentioned, connected to one wire of the supply, but the other wire is connected, not to a carbon rod, but to a fine rod of metal, held in a suitable holder, so as to protect the workman from the heat and the danger of electric shock. When the end of the rod is put close to the join the heat of the electric arc melts the metal of the rod into the edges of the plates, or whatever is being

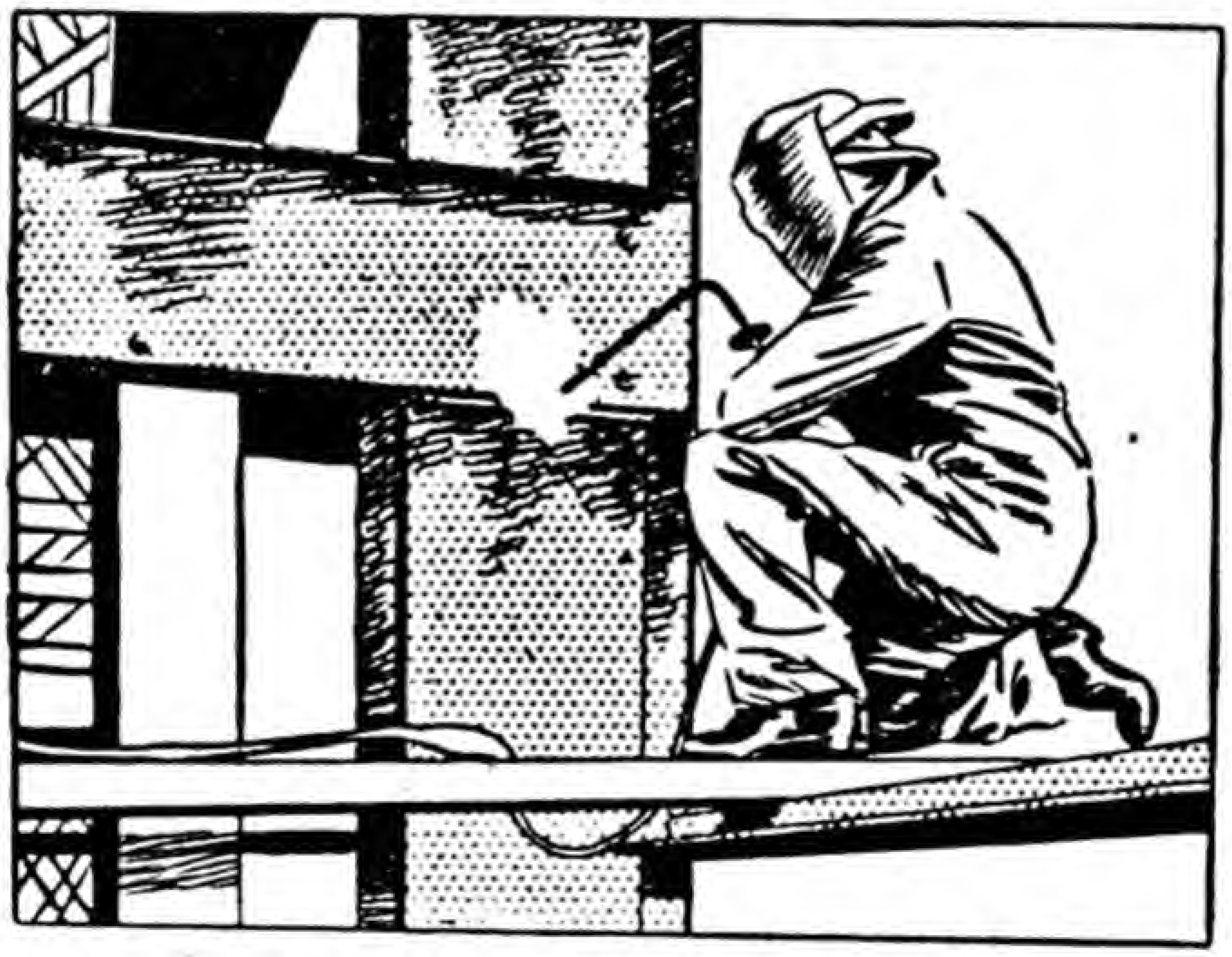


FIG. 3.—*Welding girders together by electricity.*

joined. The rod, of course, gets used up, and a fresh one has then to be supplied. The picture shows a man welding the steel girders of a building together. This is often done in New York, as, for one thing, it saves the terrible noise of riveting. There are still other methods of electric welding which can be used to join metal tubes or rods together.

As we are talking of welding, we may mention yet another method, although it has nothing to do with electricity. In this a very fine hot flame, made by burning

a gas called acetylene with oxygen, is used. The flame is as fine as a pencil, and can be used to soften the metal just where it is wanted. The picture shows men using this method to repair a broken motor-car axle.

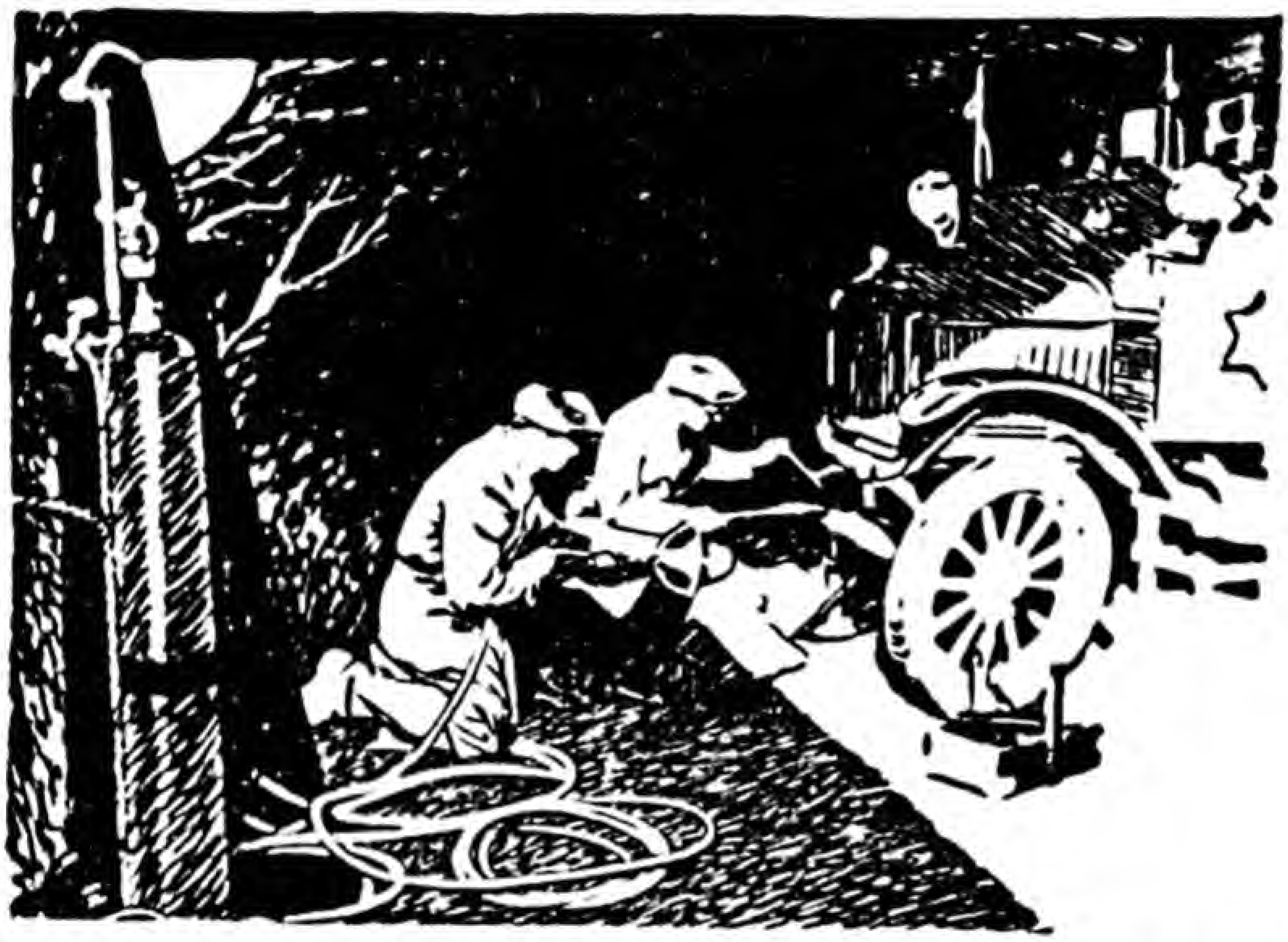


FIG. 4.—*Welding a broken axle with an oxygen-and-acetylene (called oxyacetylene) flame.*

If we now ring the electric bell at the door and go into a private house, we are pretty sure to find a wireless set, giving out music, say, which is actually being played by an orchestra perhaps hundreds of miles away. This is done entirely by electricity, the sound being turned, by various electrical processes at the sending end, into electric waves, which travel out and are turned back into sound by another set of electrical processes carried out in the receiving set. We may also find a telephone, which is once again an electrical affair; and possibly a telegram lying on a table, which reminds us that telegraphy is another application of electricity. It may have been sent from a ship at sea, and so bring to mind the way in which ships

can communicate with one another by wireless telegraphy, which has saved so many lives. Perhaps there will be an electric cooking stove and an electric iron as further examples of the use of the heating which can be produced by electricity.

FIG. 5.—*Uses of electricity in the home.*

If we call at a hospital we shall find an important department in which X-rays are used to take photographs of people's bones, and of other structures inside the body, as illustrated in Fig. 58 of Book II. This is another application of electrical discoveries. There will also be various kinds of special electric lamps, the light from

which is used to cure diseases, as well as electrical apparatus for producing special currents used for helping sufferers. Another important use of electricity by doctors is described later in the section on animal electricity, where we speak of the cardiograph, which is used for examining the beating of the heart.

Talking pictures offer another example of the application of electricity to the service of man. It is, in fact, interesting to go through a week of your life, in imagina-

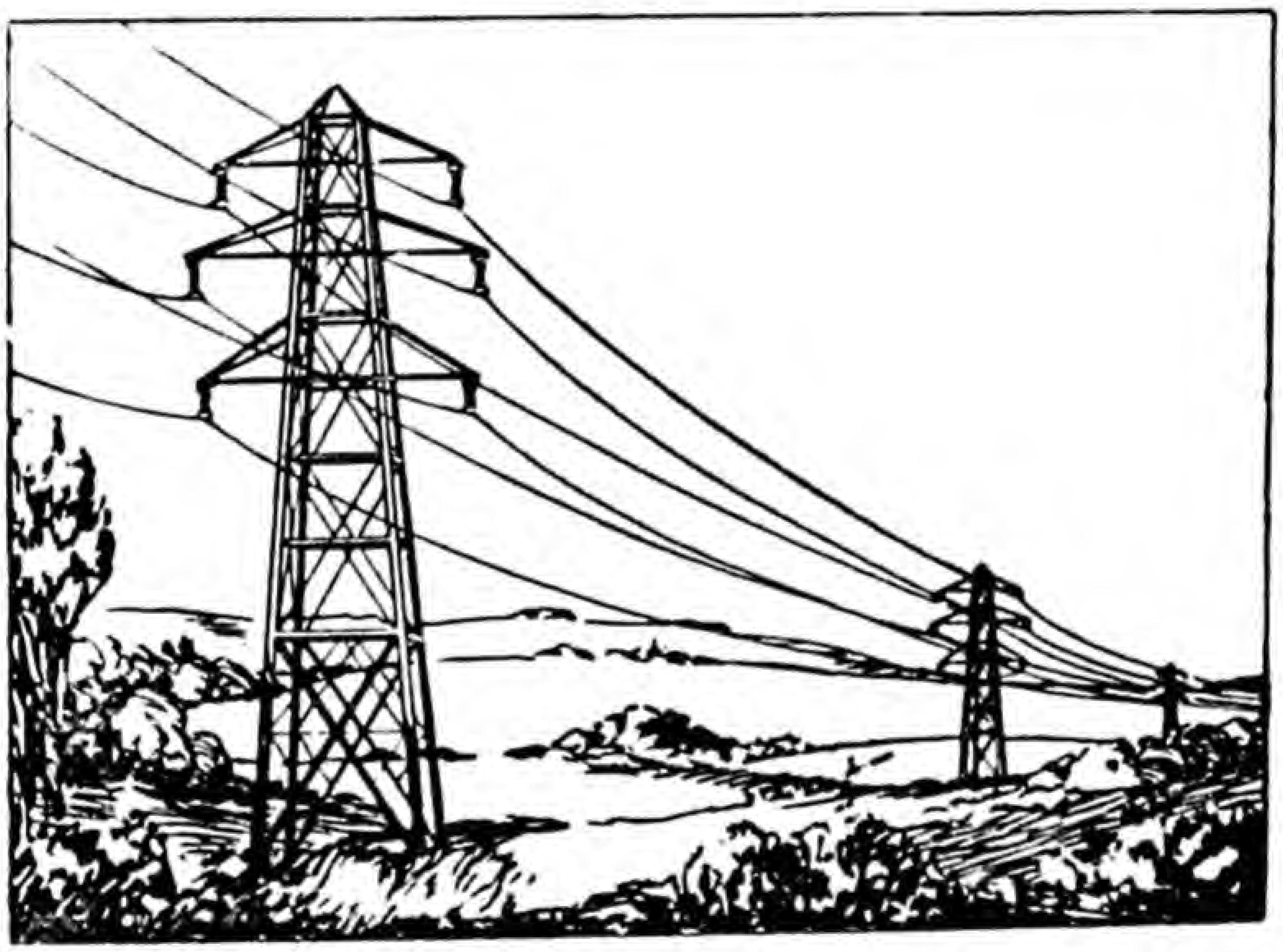


FIG. 6.—*A part of the system of wires which carry electricity all over England. This system of wires is usually called the grid*

tion, and to see when you meet some application or another of electricity in one of its branches. Whether you are resting or playing, sick or well, at home or travelling, you are, if you live in a town, continually relying upon some device or other, big or small, which is founded upon the laws of electricity. Even in the country electricity is being more and more utilised. England is being covered with a network of wires, carried on high structures called pylons, which is designed to carry electricity for lighting

and for working machines into all parts of the land. The telephone and wireless sets are becoming more and more familiar in remote places. At the end of the last century electric light was still regarded as something of a luxury for the rich; now it is at the service of all.

Electricity in Nature

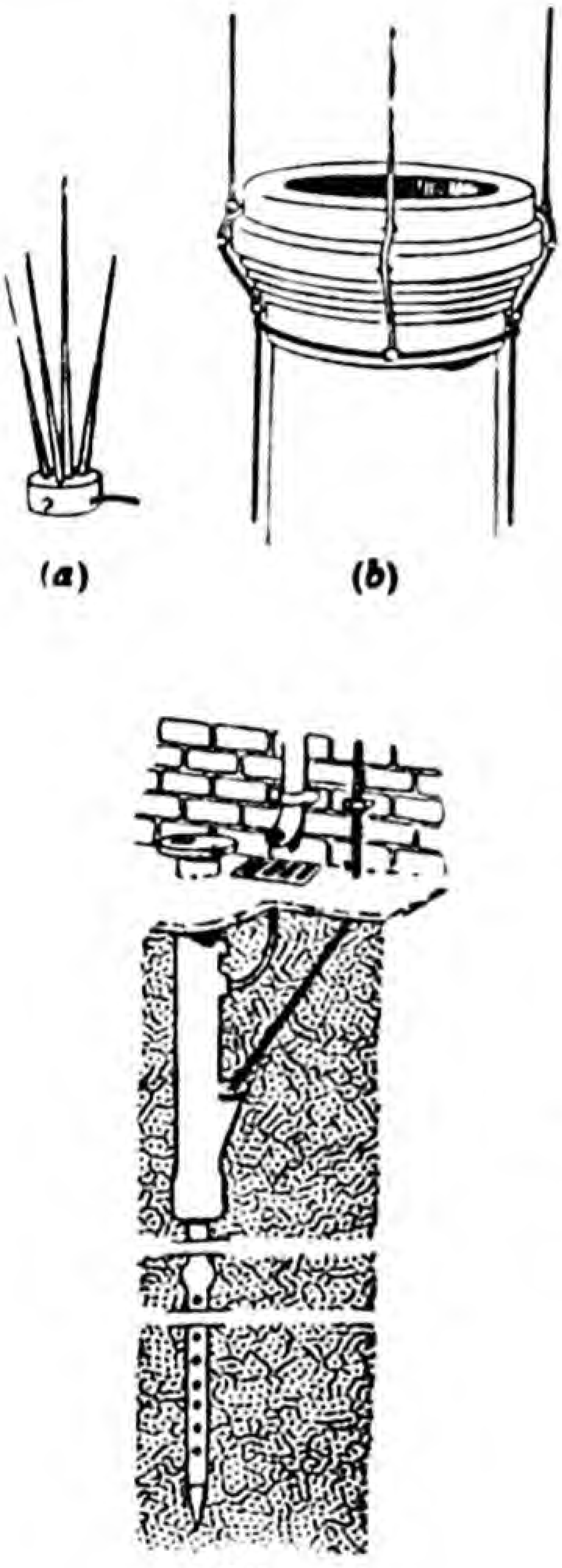
So far we have only mentioned the uses which man has made of electricity. Electricity, however, plays a great part in the weather, and is produced in the processes of nature. The most striking display of nature's electricity takes place in a thunderstorm. A flash of lightning is nothing but a great electric spark, and the thunder is the sound which it makes in passing. The thunder belonging to a particular flash is always heard some little time after the flash is seen, because, while the light from the flash travels to the eye almost instantaneously,[1] sound travels about 1,100 feet in a second. If, therefore, we see a brilliant flash and do not hear the thunder begin until 5 seconds later, this means that the flash was about 1 mile away.

Fig. 7.—*Flashes of lightning.*

In general, the flash passes from a cloud to some object, such as a tall tree or a lofty building, that stands up above its surroundings. For this reason it is dangerous to take shelter under a tree, especially a single tree in a field, during a thunderstorm, for such a tree is likely to be

[1] Light travels at the enormous rate of 186,000 miles in a second, so that the time taken to travel a few miles is far too small to be noticed except by the use of special methods and the most delicate instruments.

struck by lightning, and, if this happens, anyone beneath the tree may be severely injured or even killed.[1] To protect high buildings, especially such pointed structures as church spires and towers with pinnacles, from being struck by lightning, they are always provided with lightning conductors. A lightning conductor is a metal rod, usually a flat band or tape of copper, which passes up the side of the building, the lower end being fastened to a plate or tube of copper buried in the earth, while the upper end, which sticks up above the highest point of the building, is a sharp spike, or is provided with a bundle of spikes,



(a) (b) (c)

FIG. 8.—*Lightning conductor.* (*a*) *and* (*b*), *different forms for the top of the lightning conductor;* (*c*), *the bottom of the lightning conductor.*

[1] If you are caught out in a bad thunderstorm, choose your place of shelter in the following order. Any of them are better than remaining out:

1. Large steel-frame building.
2. Dwellings or other buildings protected by lightning conductors.
3. Large unprotected buildings.
4. Small unprotected buildings.

When inside stay away from fireplaces, stoves, and other metal objects. If you have to stay out, keep away from:

1. Small sheds and shelters in an open exposed position.
2. Single tall trees.
3. Wire fences.
4. Hilltops and wide-open spaces.

A grove of trees or dense wood, the foot of a steep cliff, or a cave are very good shelters.

called an "aigrette." The lightning then passes harmlessly down the metal band instead of striking the building itself.

We shall see later how short electric sparks can be produced by very simple means, as, for instance, by rubbing certain kinds of bodies. Lightning flashes are so much bigger and more impressive than the kind of electric sparks that can be produced in this way that it was a long time before people came to realise that they are really the same kind of thing. A very striking experiment was performed in the year 1752 by Benjamin Franklin, to show that the electricity in the atmosphere was of just the same nature as the electricity that can be produced by rubbing bodies. He made a kite out of a large silk handkerchief and two sticks provided with iron points, and, with the help of his son, flew it while storm clouds were passing overhead. At the end of the string was a metal key, and to the key was fastened a silken cord which the boy held. As we shall see, electricity will not pass along silk. He then found that he could draw sparks from the key exactly similar to those which he could make by rubbing things; that is, he showed that ordinary electricity could be drawn from a cloud. Of course, his small kite only collected a small part of the electricity of the thunder-cloud: the thunder-cloud, left to itself, manu-

FIG. 9.—*Franklin and his kite.*

factures electricity until it contains so much that the huge spark, which is lightning, passes through the air.

Although in Franklin's days only short sparks could be produced in the laboratory, to-day, with the installations that produce a million volts, sparks 12 or more feet long can be produced, which look very like a lightning flash.

FIG. 10.—*A long spark, such as is produced in places where they test the electrical strength of materials. The man is put in for comparison; he could not really stand so close.*

Another very striking appearance which is connected with the electricity of the atmosphere is the aurora borealis,[1] or northern lights. These are seldom seen as far south as England, but are a common spectacle in the northern parts of Norway, and in other regions near the North Pole. They are also seen in the neighbourhood of the South Pole, but as there are fewer people living in these regions, less is known of the southern lights. They consist of a soft glow of light, high up in the air, which takes many forms and colours: they may be in the shape of arches, bands, curtains, or rays, to mention some of the common shapes, and white, yellowish, or of other colours, particularly red and green, if the lights are bright. These are really a form of electric light, and resemble in their general nature the red glow in the lamps, known as neon lamps, which are

[1] Latin for "northern dawn."

often made in the form of tubes of various shapes, and used for advertising. In both cases the light is due to electricity passing through a gas at low pressure. In the case of the natural lights the gas is the atmosphere, which is at very low pressure at the height of fifty miles or

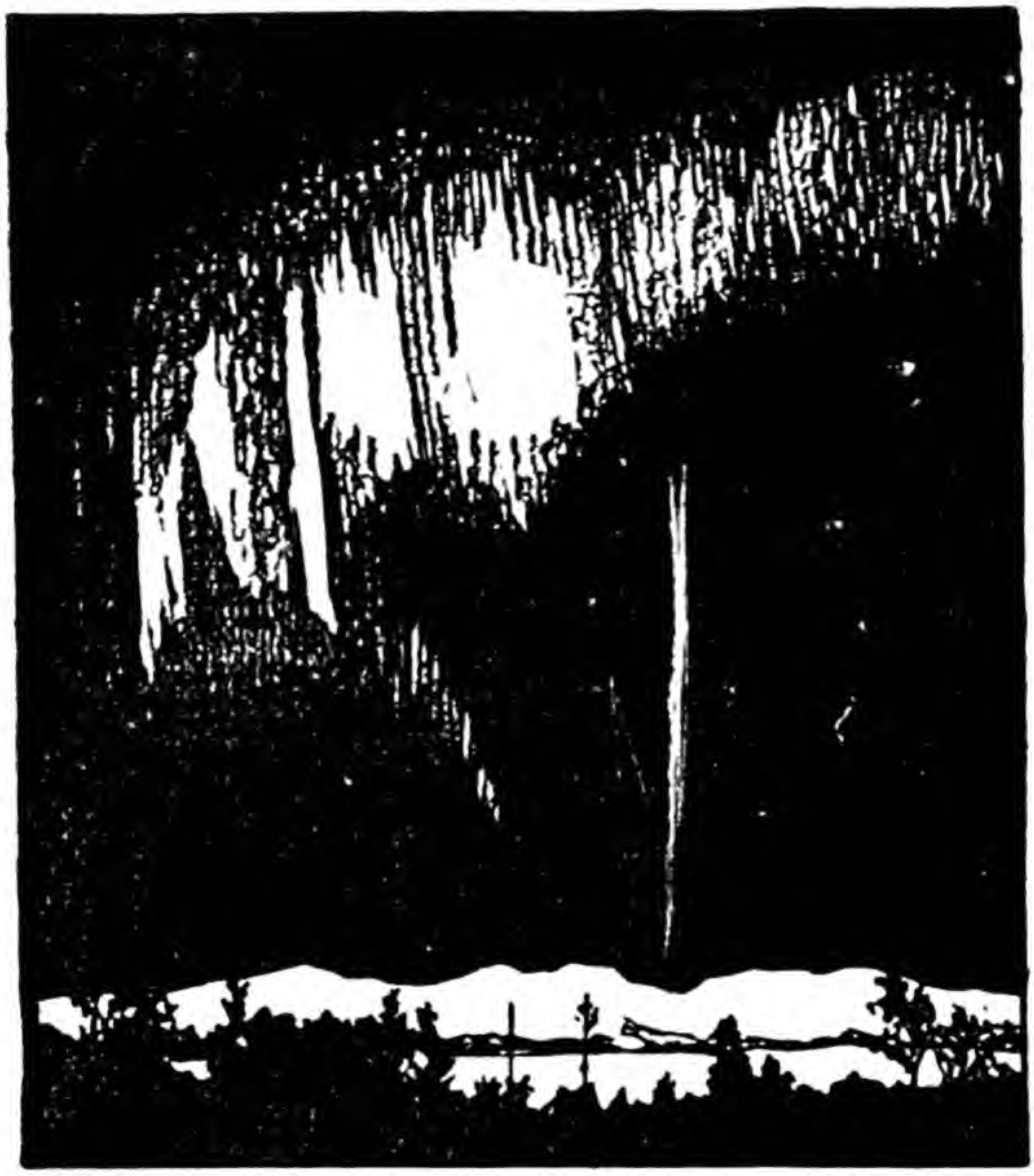


FIG. 11.—*Aurora Borealis.*

more at which the aurora takes place. In the lamp case, the gas is one called neon, which carries the electric current particularly easily.

Lightning and the polar lights are particularly striking ways in which the electricity of nature shows itself, but there are many other ways, revealed by delicate scientific

instruments, in which the presence of electricity in the atmosphere, of exactly the same kind as ordinary electricity, can be clearly shown.

Animal Electricity

Everybody knows that, under certain conditions, electricity can give a shock which may be quite mild, or which may be severe enough to kill a man, according to circumstances. An ordinary two-volt accumulator, for instance, will not give any shock that can be felt if the two poles are grasped, one with each hand, but if a wire is attached to each pole and the two wires put near one another on the tongue, which is very sensitive, a sharp tingling and an acid taste will be felt. There is no danger in this little experiment, as long as a two-volt cell is used. The little high-tension cells used in many wireless sets will give a sharp shock that can be felt with the hand, but is not dangerous. (Not more than 100 volts should be tried in this way.) Circuits of 240 volts or more are quite dangerous, and it is well known that in America the death sentence on criminals is inflicted by a powerful electric shock instead of by hanging.

Now there exist certain fishes which can give very powerful electric shocks. The most famous is, perhaps,

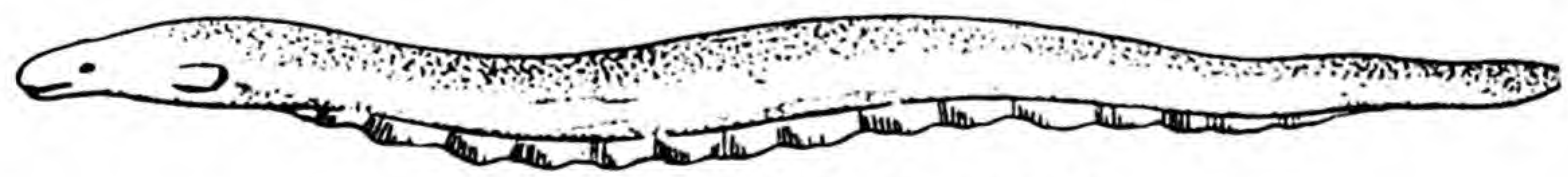


Fig. 12.—*The electric eel.*

the electric eel, or Gymnotus, which lives in small rivers in the northern parts of South America. It is often 3 or 4 feet long, and as thick as a man's thigh. This fish can

give a powerful shock to any animal in the water close to it, sufficient, for instance, to stun and kill fish, and to be very unpleasant to a man. The famous traveller and man of science, Humboldt, reported that the Indians of the parts where these fish are found are fond of eating them, and that, before trying to catch them, they drive horses into the water. The Gymnotus exhausts its electric power in giving shocks to the horses, and can then be taken without harm. Another well-known electric fish is the electric ray,[1] or torpedo, as it is also called. There is one of these fish in the aquarium at Monaco, in a special tank. On payment of a small sum the visitor is allowed to put his hand in the water, and receive the pleasure of a little shock, much less powerful than that given by the Gymnotus. Various other kinds of skates and rays can give still smaller shocks.

The great Faraday carried out many experiments on a Gymnotus in an aquarium, and was able to show that the electricity of the fish produced exactly the same effects as the electricity which the man of science uses in the laboratory—in other words, that it is ordinary electricity. People used to talk of animal electricity as if it were a special kind of electricity; it is not, it is merely electricity produced in an unusual way.

The electric eel has in its body a special organ, which takes up a large space in its body, and consists of plates of a kind of muscle, for producing electricity. The electric ray has an electric organ which consists of columns of the same unusual kind of muscle, shown cut across in the

[1] This ray has nothing to do with a ray of light. There is a large class of flat fish with long tails which are called skates or rays. The fins of the common ray are much eaten in France, with black butter—"raie au beurre noir."

picture. The other electric fish have living batteries of smaller size in them. While a few fishes are the only animals that give actual electric shocks, every animal produces electric currents on its body, but these are usually so small that it requires very delicate instruments to show that they are there. If a man, for instance, puts

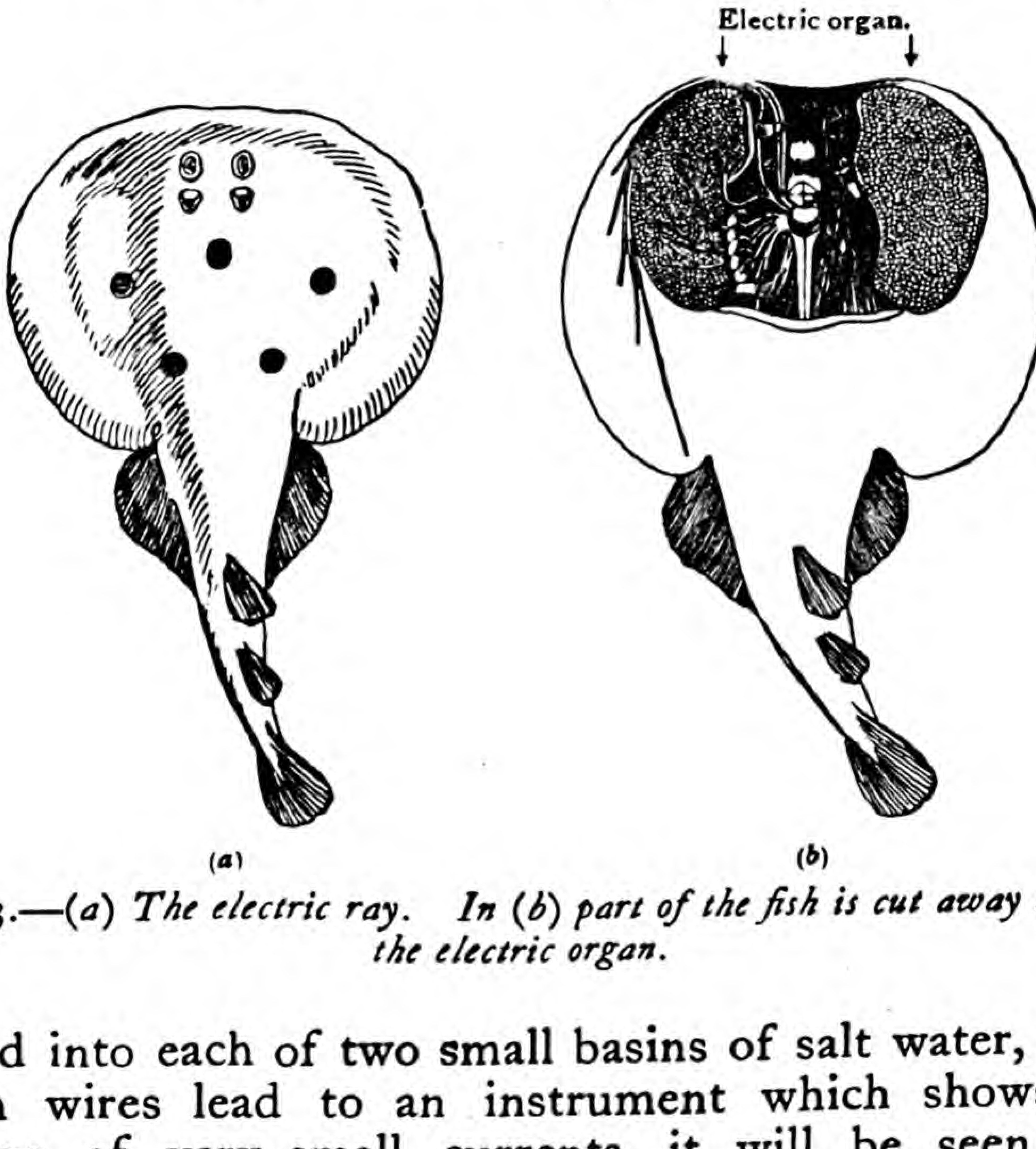
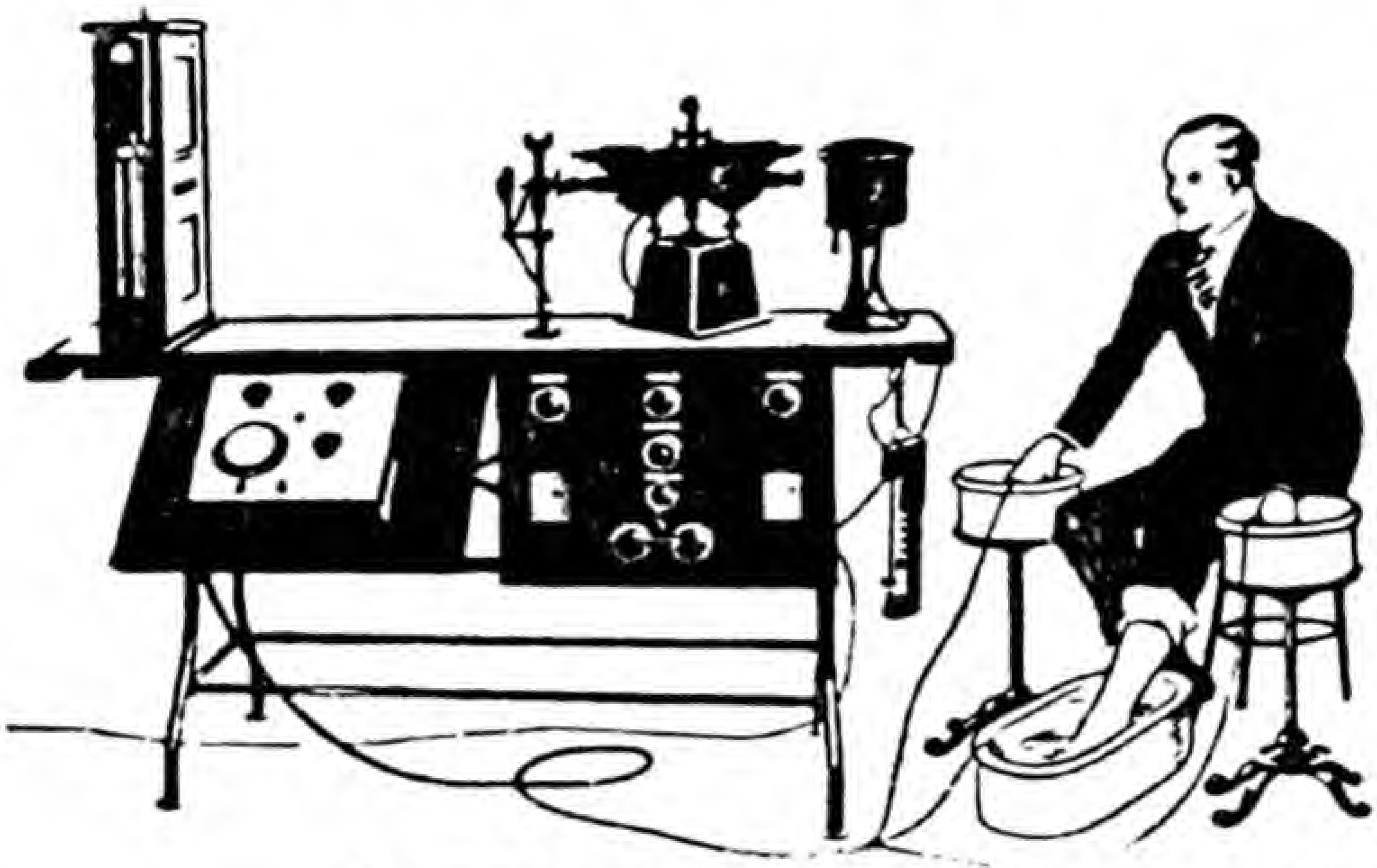


FIG. 13.—(*a*) *The electric ray. In* (*b*) *part of the fish is cut away to show the electric organ.*

a hand into each of two small basins of salt water, from which wires lead to an instrument which shows the passage of very small currents, it will be seen that each heart-beat is accompanied by a little current of electricity. This instrument follows exactly the way in which the tiny current rises and falls, and, by photography, draws a line, called a cardiogram, showing the

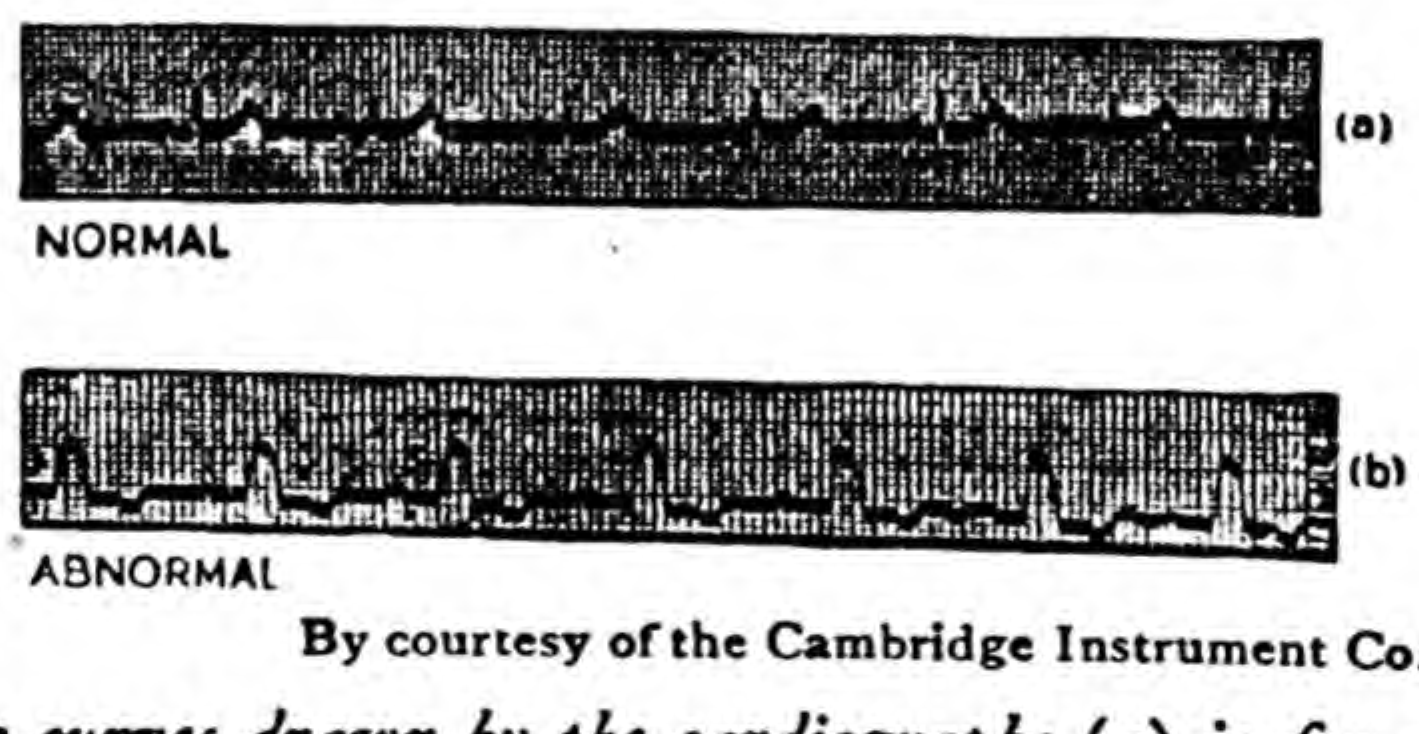
ups and downs. This line has a different shape for a person with a sound heart and for a person with heart disease. The little electric currents which our



By courtesy of the Cambridge Instrument Co.

FIG. 14.—*The cardiograph, for testing heart-beats by electricity.*

bodies generate are, then, a very important guide to the behaviour of the heart, and great use is made of the cardiogram by doctors who pay special attention



By courtesy of the Cambridge Instrument Co.

FIG. 15.—*Two curves drawn by the cardiograph: (a) is for a healthy heart; (b) is for an unhealthy heart. The difference is quite clear.*

to the heart. They serve to remind us that in any animal small electric currents are ceaselessly flowing.

A muscle, in fact, has the power of contracting and doing

work, and also of producing electricity. The ordinary muscles of our bodies, and of the bodies of most animals, are particularly good at doing work, and very bad at producing electricity. On the other hand, the special muscular organs in the electric fishes already described are very weak indeed for the purposes of moving parts of the body, but are very good at producing electricity. They are muscles that have developed in a particular way which gives a great advantage to the electrical side, at the expense of what may be called the mechanical side.

A suitable current of electricity, applied in the right place, will make a muscle contract, either in a living or in a dead body. This is often of great use in treating people who, owing to illness or injury, have a muscle so wasted that it will not work properly. The doctor or his assistant can make the muscle contract, by electricity, and after this has been done several times the patient usually finds that he can contract the muscle himself without aid. It is clear, then, that the study of electricity is very important from the point of view of understanding how our bodies work.

What have we learnt so far, then? That not only is electricity, as manufactured by man, serving us in the most varied ways in our daily life, but also that electricity, of exactly the same kind, is manufactured in the atmosphere and plays a great part in weather conditions, and that electricity, still the same electricity, is manufactured in the bodies of all animals. More than this, modern science, by a series of experiments and arguments which are too difficult to be discussed in a little book like this, has shown that electricity is, in the end, responsible for all the varied kinds of light that we know, the light of a flame as much as that of an electric lamp, and is built

up as a part of every little bit of matter, solid, liquid, or gas, in the universe.

To help to understand the many different ways in which electricity can appear we may consider the behaviour of water. Water, exactly the same kind of water, can produce very different effects and impressions, according to the way in which it is divided up, or moving. It can appear as a broad river, a tropical rain, a soft shower, a drifting mist, a pond or a waterfall, but in all cases it is just water. In the same way electricity, exactly the same kind of electricity, can produce very different effects according to the conditions, such as the amount of electricity and the way in which it is moving. Electricity, we may say, is at the bottom of everything. Clearly, then, it is worth while to spend a little trouble to try to learn something about its ways.

Frictional Electricity: Conductors and Insulators

The most familiar aspects of electricity nowadays are connected with what are called electric currents. When we move a switch to turn on the electric light, for instance, we say that a current of electricity flows through the lamp, or when we connect up an accumulator to a toy motor, we say that a current flows through the motor. The simplest way, however, to produce electricity is by rubbing certain materials with certain other materials. While electric currents were not obtained and used until the beginning of last century, the ancient Greeks, some hundreds of years before Christ, knew that amber,[1] if

[1] Amber is a yellow, hard fossil resin from trees that lived hundreds of thousands of years ago. It is found on many seashores, especially, nowadays, the shores of the Baltic. Most of the so-called "amber" cigarette-holders are, however, imitation. Some of them electrify on rubbing, but not so well as real amber.

rubbed vigorously with a woollen cloth, attracted small pieces of straw or feather, hairs, or other light objects. As the Greek word for amber is *electron*, this power of attraction, which certain things show when rubbed, was called electricity by Gilbert, Queen Elizabeth's doctor, who found out a great deal about electricity and magnetism. The name has been used ever since. Since friction and rubbing are the same thing (the Germans have only one word for both), electricity produced in this way is usually called " frictional electricity " in English.

In Book I we carried out a few experiments with a rubbed stick of sealing-wax, which is easier to come by than amber and acts just as well. We learnt that the rubbed wax would attract little bits of paper, or a pith ball hung on a very light thread of silk, which should not be the twisted silk used for sewing, but a thread unravelled from a mass of unspun silk. Another pretty way to show the attraction is to make a paper hoop by pasting together the ends of a slip of paper about nine inches long and half an inch broad. If it is neatly made, and rolls easily, it will follow the rubbed stick of sealing-wax all over a smooth table. With nothing more than some rods of different substances, such as ebonite, sealing-wax, glass,[1] copper, and iron, say, and a dry woollen cloth as a rubber we can learn some further important facts about electricity.

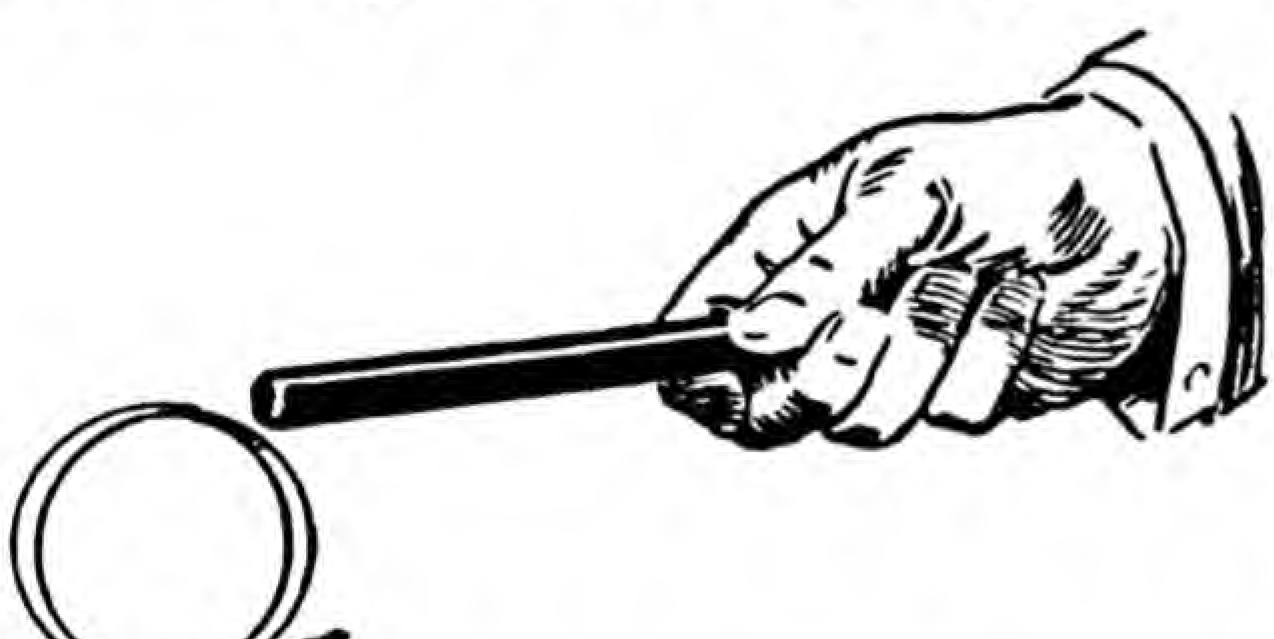


FIG. 16.—*The paper hoop.*

[1] The best kind of glass is hard flint or lead glass, and not the soft soda glass so widely used for tubes and rods in the laboratory.

For the first experiments we will use the property of attracting little scraps of tissue paper to show whether electricity is present or not. We rub in turn, the ebonite rod, the sealing-wax, and the glass, with the woollen cloth, and find that not only will each rod attract the bits of paper or bits of hair or other light objects after rubbing, but that the part of the cloth itself that has been rubbed against the rod will also attract the scraps. The rods and the cloth should be thoroughly dried by warming for some time in front of a fire, or close to a radiator, especially if the weather be wet, as, for a reason that we shall see later, the experiments will not work if the objects be damp. The ebonite and sealing-wax must not be made too warm, or they become soft, or, if hotter still, catch fire, but the glass rod may, before use, be made as hot as can conveniently be held.

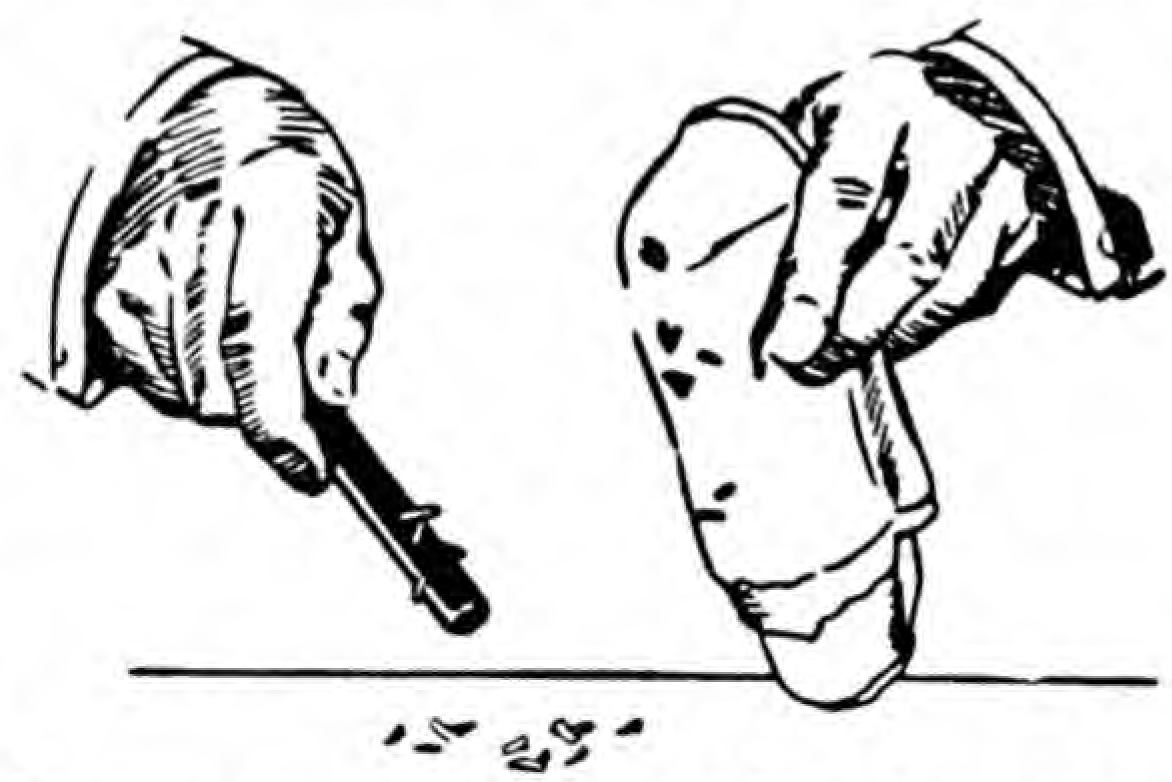


FIG. 17.—*Attraction by ebonite rod and by flannel.*

If now a metal rod or tube, say a brass tube about half an inch in diameter, be held in the hand and briskly rubbed, it will be found that no attraction can be produced, either by it or by the cloth. Suppose, however, that instead of using the bare hand to hold the rod we wrap it round with several layers of dry silk handkerchief at one end, and hold it by that, or, better still, provide it with an ebonite handle by, for instance, jamming one end into a hole bored in a stout rod of ebonite, or into an ebonite tube. If the metal be now rubbed it will be found that both it and the cloth will attract fragments as before,

although not so strongly as does sealing-wax, for instance. All bodies, it has been found, will become electrified by rubbing, only certain ones require a silk or ebonite handle if the attractive power is to show itself. Why is this?

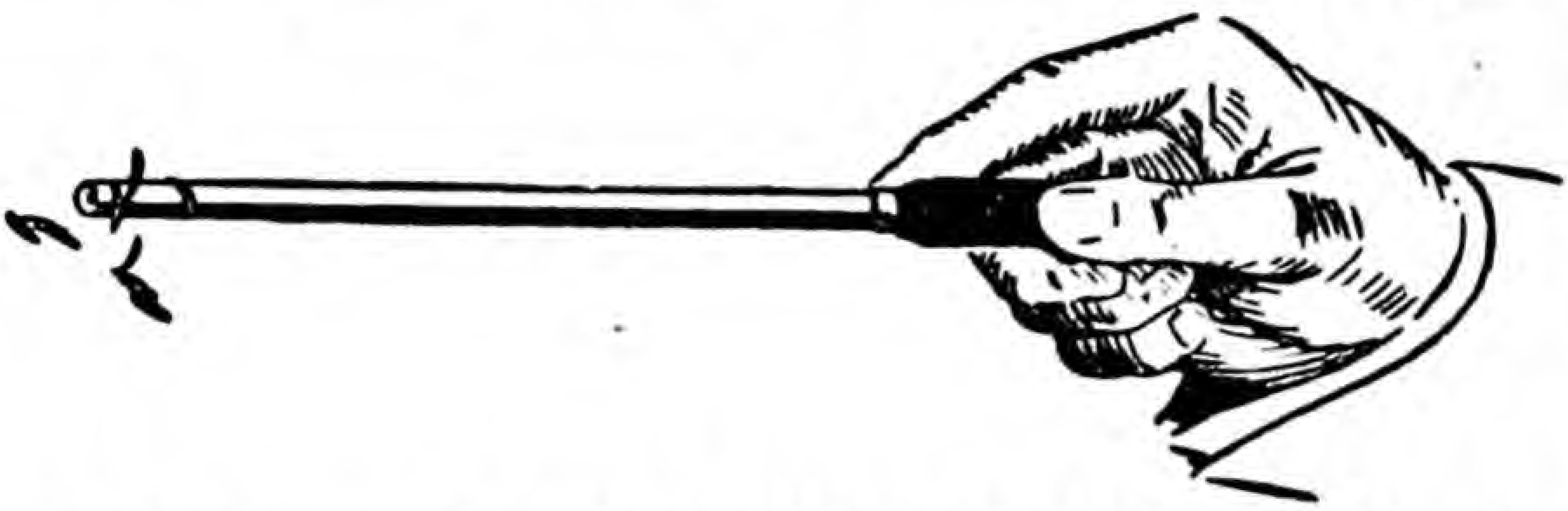


FIG. 18.—*Attraction by rubbed metal rod, held in an ebonite handle.*

This question leads us to divide bodies into two very important classes, but before talking of this we will carry out another simple experiment. We hang up a metal rod horizontally by two loops of dry uncoloured silk ribbon (which should be washed if new, to remove any dressing, and then well dried). Under one end we put a few light scraps of feather or paper, and then rub a stick of ebonite well, and draw it gently over the other end of the metal rod, so that part of the electricity of the rod is given to the metal. At once the scraps are attracted. If, however, we hang up the ebonite rod, or a well-dried glass rod, and electrify one end with our rubbed stick of ebonite, the other end will not attract light scraps. The electricity runs all over the copper rod, but stays just where it is put on the glass or ebonite rod.

Why does the copper rod electrify when rubbed if it is provided with an ebonite handle, and not if it is held in the hand? The rubbing produces electricity in both cases, but the electricity escapes through the body if the bare hand touches the rod; it cannot, however, pass along the ebonite handle. Why can a glass or ebonite rod be

held in the hand and electrified by rubbing? Because the electricity cannot pass along the rod to the hand. The two classes of bodies are, then, those that let electricity pass along them, and those that will not. All metals belong to the former class; glass, sealing-wax, shellac, silk, amber belong to the latter. The things that let electricity pass through them are called *conductors*, the others are *non-conductors*, or *insulators*. We say that a body so arranged that the electricity cannot run away from it is insulated. A brass ball on an ebonite stand is insulated. The human body, which is mostly water, is a conductor.

Ordinary water is a conductor. Unless the day is very dry, a thin invisible film of water from the atmosphere always forms on the surface of ordinary glass, and the glass therefore does not insulate well. This is why glass rods have to be dried by heating before you can do good electrical experiments with them. The flannel rubber will also become slightly moist in ordinary weather, and should be carefully dried. You will often see the moisture rising from it as a mist when it is placed in front of a hot fire.

Everybody nowadays knows that electric currents, of which we shall speak in Chapter II, are carried by copper wires, for copper is a particularly good conductor. If two copper wires touch one another, or if two turns of the same copper wire touch one another, the electric current runs across at the point where they touch, and does not continue in the path along the wire which it is required to take. The copper wires that carry currents in scientific apparatus are therefore usually covered with an insulating covering, which may be cotton, which is a fairly good, but not very good, insulator; silk; indiarubber; or some other good insulator which bends easily. With modern

machinery, wire can be very easily covered with an insulating substance, but in the early days of electricity the experimenters had to cover their own wire, which was a long and tedious job. Joseph Henry, an American man of science (born in 1797 and died in 1878), whose work led to, among other things, the invention of the telegraph, spent months in wrapping wire with strips of cloth, so that he could wind the wire on an iron core to make an electro-magnet, as described in the next chapter.

The fact that the passage of electricity can be stopped by a thin layer of insulator is at the bottom of all our electrical machinery; it means that we can make the electricity travel just where we want it to with the greatest ease. No other agency for transmitting power can be guided as easily as electricity. If one of the wires carrying the current to an electric motor is cut squarely, and the two ends separated by a sheet of mica, which is a very good insulator, or even a sheet of dry paper, the motor will stop: the current cannot flow through the paper. If, however, we were to place a sheet of paper, or even a sheet of thin steel, across a pipe which was conveying water or steam or compressed air to a big engine, it would be broken at once. It would require a very strong obstacle placed in the steam-pipe to stop a locomotive, but a strip of any one of the thin, tough, insulating compounds which are made to-day, wound round the little wheel which leads the current into an electric train, would stop the vehicle. Even a sheet of paper would do it, if it were not broken.

When we are dealing with frictional electricity we must have very good insulators, for the quantities of electricity are very small, and a small leak allows all of it to run away. For current electricity we do not require such good insulators, because with a large supply of electricity a

very small leak hardly matters. A very fine crack in a small bottle of something precious, say scent or wine, is a very serious matter; but a crack of the same size in an iron water-main would not affect our water-supply much.

Electrical Attractions

In Book I we showed how a simple pivot could be made by resting a piece of flat glass on a watch-glass (Fig. 43, Book I). Another way of supporting a body so that it can turn easily, and a way very much used in science, is to hang it up by a fine wire or thread. We will use this method in some experiments which we will now describe. As we want the body to be insulated, we will use not a metal wire but a fine silk thread, selected from a mass of unspun silk. Sewing silk is too thick, and is made with such a twist that it gives trouble by slowly unwinding.

As we want to hang up a rod we will make a little double hook of wire, as shown, and hang that up. We

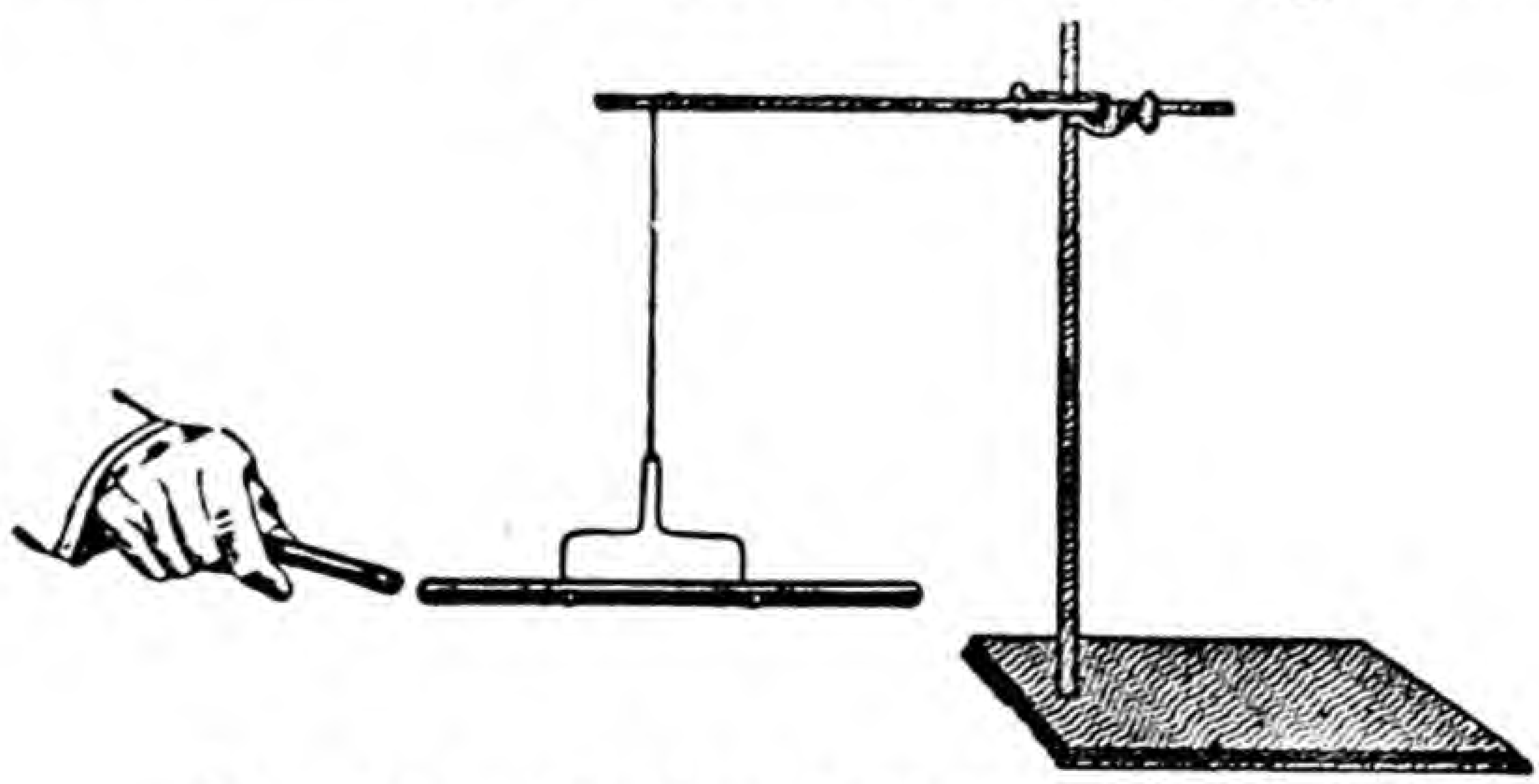


Fig. 19.—*To show electrical repulsion.*

now rub a sealing-wax rod with a dry old silk handkerchief, and place it carefully in the holder, so that it balances and can turn freely. If we rub a second stick of sealing-wax and hold it near the rubbed end of the first

stick, we shall find that it appears to push the suspended stick away. We say that two rubbed pieces of sealing-wax repel (that is, push away) one another.

If, however, we rub our glass rod, which has been well dried by heat, and hold the rubbed end near the freshly rubbed and suspended sealing-wax, the two try to approach one another. Rubbed sealing-wax and rubbed glass attract one another.

We can repeat the experiment with other substances, such as a rod of ebonite and a rod of sulphur, which can be made by pouring melted sulphur into a glass tube and removing it when cold. The ebonite and the sulphur will be found to behave like sealing-wax. If a rod of amber, say a real amber cigarette holder, can be obtained, it also will behave as ebonite does.

The question remains how the two pieces of rubbed glass behave. By hanging one up we can soon show that they repel one another.

There are, then, as far as attractions and repulsions are concerned, two kinds of electricity, which we may call glass electricity and ebonite electricity. They are also called vitreous electricity and resinous electricity, because vitreous means glassy, while resin behaves like ebonite. The usual habit of men of science, however, is to speak of vitreous electricity as *positive*, resinous electricity as *negative*. There is no particular reason for choosing vitreous to be positive; if the early workers had decided to call it negative it would have been equally suitable, and then resinous would have had to be positive. The point is that the two kinds of electricity behave in opposite ways.

What, then, is our rule? A charge of positive electricity repels a charge of positive electricity; a charge of

negative electricity repels a charge of negative electricity; but a charge of positive electricity attracts a charge of negative electricity. We can make this into quite a short rule: *like* charges repel one another, but *unlike* charges attract one another. We shall find out a similar rule about magnets in Chapter III.

Let us once more rub our stick of ebonite in a fold of the silk handkerchief, hang up the ebonite and hold the rubbed part of the silk to it. Attraction will take place. If, however, we hold the rubbed silk to a glass rod which has been rubbed with a different piece of silk, the two will repel one another. This and other experiments show that when we rub two substances together one becomes positively, and the other negatively charged. It can also be shown that the quantities of positive and negative electricity so produced are just sufficient to cancel one another—that is, together they produce no result. It is something like what happens if we dig a hole in flat ground: we get a hole and a heap of earth, the amount of hole being just equal to the amount of heap. If we put them together we get flat ground again.

In rubbing two bodies together, then, we do not create electricity, we separate out the positive and the negative, which, when they exist together, just cancel one another. We must think of all ordinary uncharged bodies as having equal quantities of the two kinds of charge: if some of the negative can be made to pass out, a surplus of positive is left, and the body appears positively charged.

Let us consider electrical attractions a little further. We know that a rod of either glass or ebonite, if rubbed with silk, attracts scraps of uncharged paper. Let us do a suspension experiment with an uncharged body: let us hang up a rod of anything, wood, sealing-wax, or glass,

but whatever it is, let us take care *not* to rub it first. Let us now rub a rod of, say, sealing-wax, and hold it near to test the effect. It will be found that, whatever the uncharged body, there is an attraction, and there will be an attraction whatever the rubbed rod is. A positive *or* a negative charge attracts an uncharged body.

We can show all the rules of attraction rather well with one piece of apparatus. A rod of ebonite and a rod of glass of the same size are fitted together into a little brass holder, as shown, and hung up by a silk thread. If

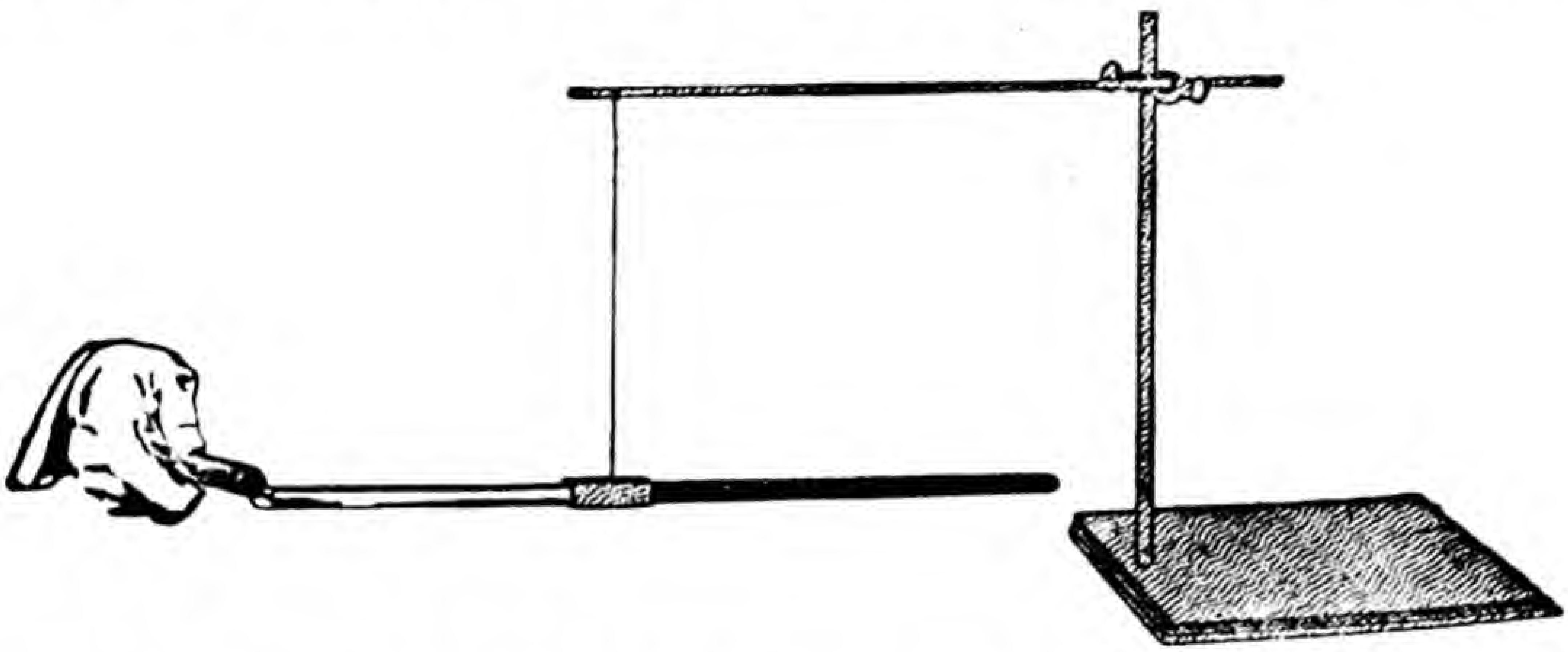


FIG. 20.—*To show both electrical repulsion and electrical attraction.*

neither of them has been rubbed, then a rubbed ebonite *or* a rubbed glass will attract either end of the suspended rod. Now let the whole be taken down, and both ends be rubbed with separate pieces of silk. When the joined rod is hung up again it will be found that a rubbed ebonite rod attracts the glass and repels the ebonite end, but a rubbed glass attracts the ebonite and repels the glass end.

Why does a charged body always attract an uncharged body? Let us think of the uncharged body as having in it, all the way through, an equal quantity of positive and negative electricity, mixed together. Suppose a positively

charged rod is brought near. It will attract the negative charges and repel the positive ones, so that the body becomes negatively charged near the positive rod, and is attracted. You can easily see what happens if, instead of a positive, a negative rod is brought near; the positive charges are brought to the part of the suspended rod opposite this negatively charged rod, and so there is attraction in this case as well. The free charges, as they are called, always appear on the surface of the body.

If, then, an uncharged body is brought near a positively charged rod a negative charge appears on the part of the body near the rod, but if the body is taken away again the charge disappears. Suppose, for instance, a ship with an equal number of men and women on board steams near a pier where there is a male film star, say, whom the women like but the men hate. All the women will go to the side of the ship near him, and all the men to the other side. When, however, the ship goes on they will mix again. If it were a female film star, whom the men liked and the women disliked, the opposite would take place. But in neither case would there be an excess of men or of women on the ship: only a separation due to an outside attraction, which disappears when the outside attraction is removed.

The charge that seems to appear on an uncharged body when a charged rod is brought near it is called an *induced* charge. If, instead of only bringing the rod near, we touch or rub the uncharged body with it, then this body gets a real charge, part of the charge of the rod. A charge actually leaves the rod, and passes to the uncharged body in this case. We can now carry out some simple experiments which make all this plain.

A metal rod with rounded ends[1] is hung up on two pieces of silk ribbon, as illustrated in Fig. 21. As a test of electrification we can use little pieces of thin paper. If we now bring a well-rubbed stick of ebonite near one end of the metal rod, but not touching it, either the far end or the near end will attract the scraps of paper, but the middle of the rod will not. This shows the separation of the charges to the ends of the rod.

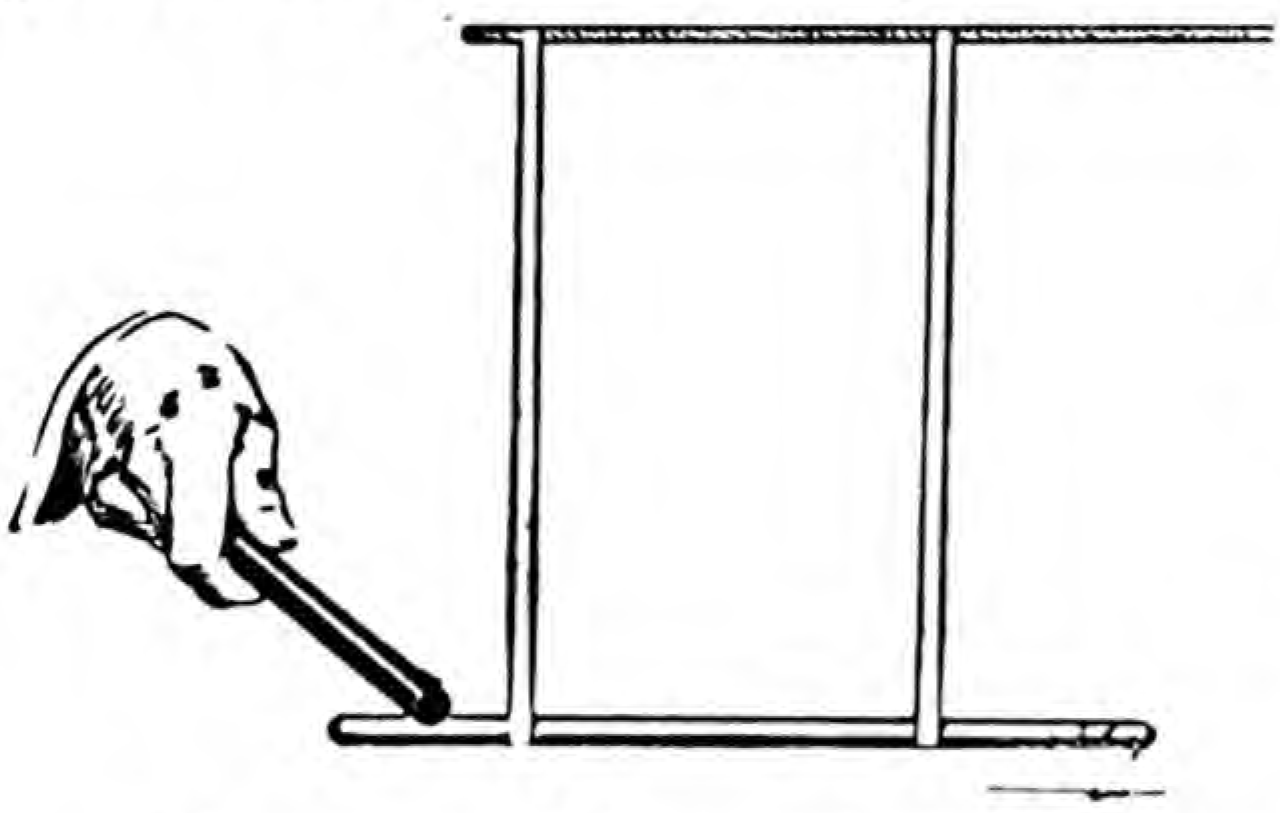


FIG. 21.—*Electric induction.*

Another simple experiment which shows the difference between an induced charge and a real charge is easily performed by hanging up a single pith ball on a long thread of silk. A wire stuck in the cork of a bottle makes quite a good stand. If we bring a rubbed ebonite rod near, it attracts the pith ball, because of the opposite induced charge on the side near the rod. As soon as the ball touches the rod, however, it takes some of the charge from it, and is therefore repelled. If a rubbed glass rod is now brought near it will strongly attract the ball, which now has a real charge. You can often see the same thing with the little bits of paper picked up by a rubbed

FIG. 22.—*The pith ball.*

1 A wooden rod pasted over with silver paper will do very well.

rod of ebonite, that they are first attracted, and then repelled, but it does not always work well, as the bits of paper do not always touch the rod well enough to take some of its charge. A pretty little toy can be made by taking the lid of a round cigarette box, putting in it some little bits of pith, and covering the box with a sheet of celluloid or dry glass. When the lid is rubbed the little pieces will dance up and down vigorously. Many people who have been amused by this do not know why it happens, but you do now.

There are many pretty tricks that can be done by the help of electrical attractions. Ordinary rubber balloons electrify very well if briskly rubbed, either by the hands (if your hands are not of the wet kind) or by a dry flannel. They can then be made to stick to the wall of the room by electrical attraction. This is, of course, the attraction by induced charges: the balloon is so large that the little bit of charge that passes to the wall at the place where the balloon touches does not matter compared to the large charges induced by the parts that do not touch. Balloons can even be stuck to the ceiling in this way and will remain there for some minutes. Or an electrified balloon may be hung up by a long thin thread, and used to show electrical attractions and repulsions.

A sheet of brown paper, well dried in an oven or in front of a fire, if placed on the wall and briskly brushed with a clothes brush, will stick by electrical attraction, and small sparks may be seen if it is pulled off in the dark. People with a good head of hair often hear a crackle if they pull off a woollen vest over their heads in winter, when everything is dry. This is due to the production of electricity by the rubbing of the wool, and small bluish sparks can easily be seen if the undressing is done in a dark room.

Electrical Instruments

We can now consider an instrument called an electroscope, which can show the effect of very small charges of electricity. It consists of a metal rod with a flat surface, say about two inches long and nearly half an inch broad, at one end. To this surface a gold leaf, of about the same size, is stuck by one end, as shown in the picture.[1] The metal rod is mounted in a box with glass sides by means of a plug made of a good insulator; clean ebonite or sealing-wax or sulphur all make good plugs. A rough electroscope may be simply made by mounting the metal rod with the leaf in an ordinary medicine bottle, by filling the neck with *clean*—not burnt or fingered—sealing-wax. It is best to have the upper end of the metal rod provided with a little round table, as shown in the figure.

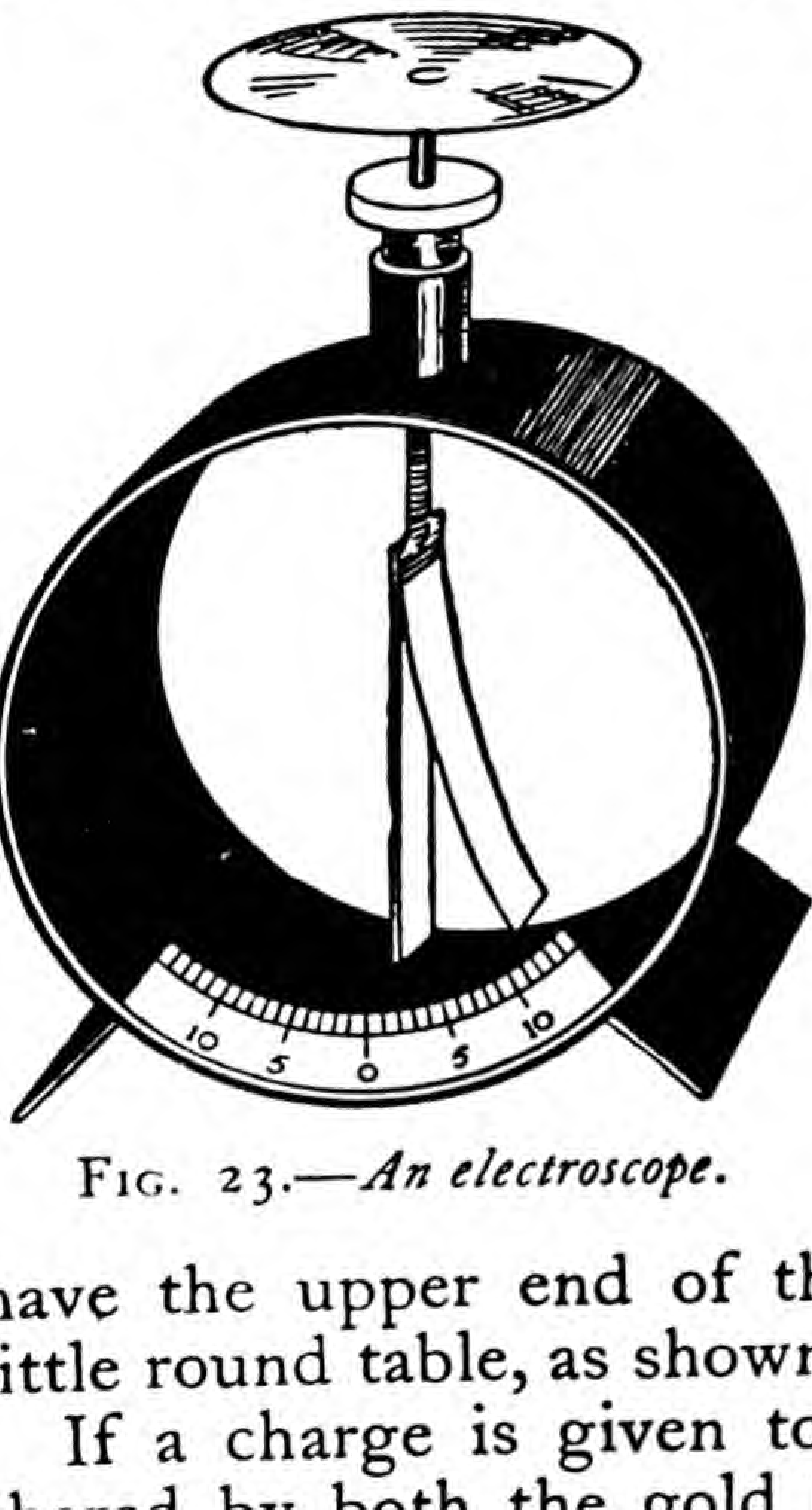


Fig. 23.—*An electroscope.*

If a charge is given to the metal, then part of it is shared by both the gold leaf and the brass opposite it. They therefore repel one another, as both have like charges, and the leaf stands out from the brass. If a rubbed rod is brought near, but does not touch, the disc,

[1] Cutting gold leaf is not very easy, but it can be done if the leaf is placed between two pieces of paper and cut with very sharp scissors. To stick it, a little spittle is as good as anything. Aluminium leaf, which is cheaper and easier to handle, can be used instead.

the leaf stands out, but falls again if it is taken away, showing the ordinary effect of an induced charge. If, however, the electrified rod is gently rubbed across the disc some of its charge passes to the metal, and remains there when the rod is taken away. The leaf should then continue to stand out. The electroscope is said to be charged. If the insulation is good the electroscope should show the charge for at least an hour, but in course of time it very slowly leaks away.

This simple type of instrument is very important to-day. Many agents, such as X-rays, cause invisible positively and negatively charged particles to appear in the air, or in other gases, and the electroscope shows their presence, since it loses its charge. If it is positively charged it attracts the negative particles, which cancel the charge: if it is negatively charged, it attracts the positive particles, with the same result. It is quite easy to show this kind of thing, for an ordinary flame, such as the flame of a Bunsen-burner, produces these positive and negative charges in the air. If such a burner is brought near a charged electroscope the leaf falls rapidly. If, by the way, you want to make sure that an ebonite or other rod with which you are working has no charge it is quite sufficient to hold it a foot or more above a flame for a few seconds. This is often useful, as, especially in very dry cold weather, bodies easily become accidentally electrified, and so produce puzzling effects when used for experiments. This discharging effect of a flame can also be shown by bringing it near a balloon or a piece of brown paper stuck to the wall by electrification: the balloon or paper will at once fall. The effect can be made more striking by blowing the air from above the flame at the balloon.

This production of invisible electrified particles is of the greatest importance in modern science. The hot wire in the wireless valve is there to produce such particles. You can show the electrical effects of a hot wire with the electroscope. Suppose a wire be stretched above the plate, and the ends of the wire connected to an accumulator and rheostat,[1] which is altered until the wire is red-hot. The leaf will quickly collapse. X-rays or radium also produce electrification in the air, which can be easily shown by the electroscope—if you have the X-rays or radium. Radium is an exceedingly precious substance (of which a gramme, that is, $\frac{1}{28}$th of an ounce, costs more than £10,000) which is very valuable for the rays which it sends out. These rays produce the electrified particles in the air so strongly that an amount of radium which you would not see, say the size of a small piece of dust, if placed anywhere near, would quickly discharge the electroscope. Radium is much used in hospitals, and occasionally a tiny tube has been lost and thrown away with ashes and rubbish. To find it again the rubbish has been brought, shovelful by shovelful, close to a charged electroscope: as soon as the one containing the radium is near, the electroscope leaf begins to fall.

The electroscope, then, simple as it is, is a very important instrument. It has been used not only to find out about X-rays and radium and the behaviour of hot wires, but to investigate many other things connected with electricity, including thunderstorms. Of course, electroscopes for special purposes are more delicate and elaborate than the one we have talked about, but the way in which they work is the same, and depends upon electrical repulsions.

[1] See next chapter.

Rubbing a stick of ebonite produces very little electricity, so that machines are made in which the effect can be carried on all the time by turning a handle, and the electricity collected. The exact way in which they work requires rather more lengthy explanation than we can give here, but it depends upon the laws of electric induction which we have explained. Such a machine, of the kind first built by Wimshurst and known by his name, is shown in Fig. 24. Rapid turning produces very powerful electrification, and large sparks like lightning flashes, accompanied by a sharp crack, corresponding to the thunder, can easily be obtained between the balls. Even a small machine can produce a spark three or four inches long. With an insulated metal plate or rod connected to one knob, or terminal, very powerful electrical attractions and repulsions can be shown, and other effects, described in the next chapter, can be produced.

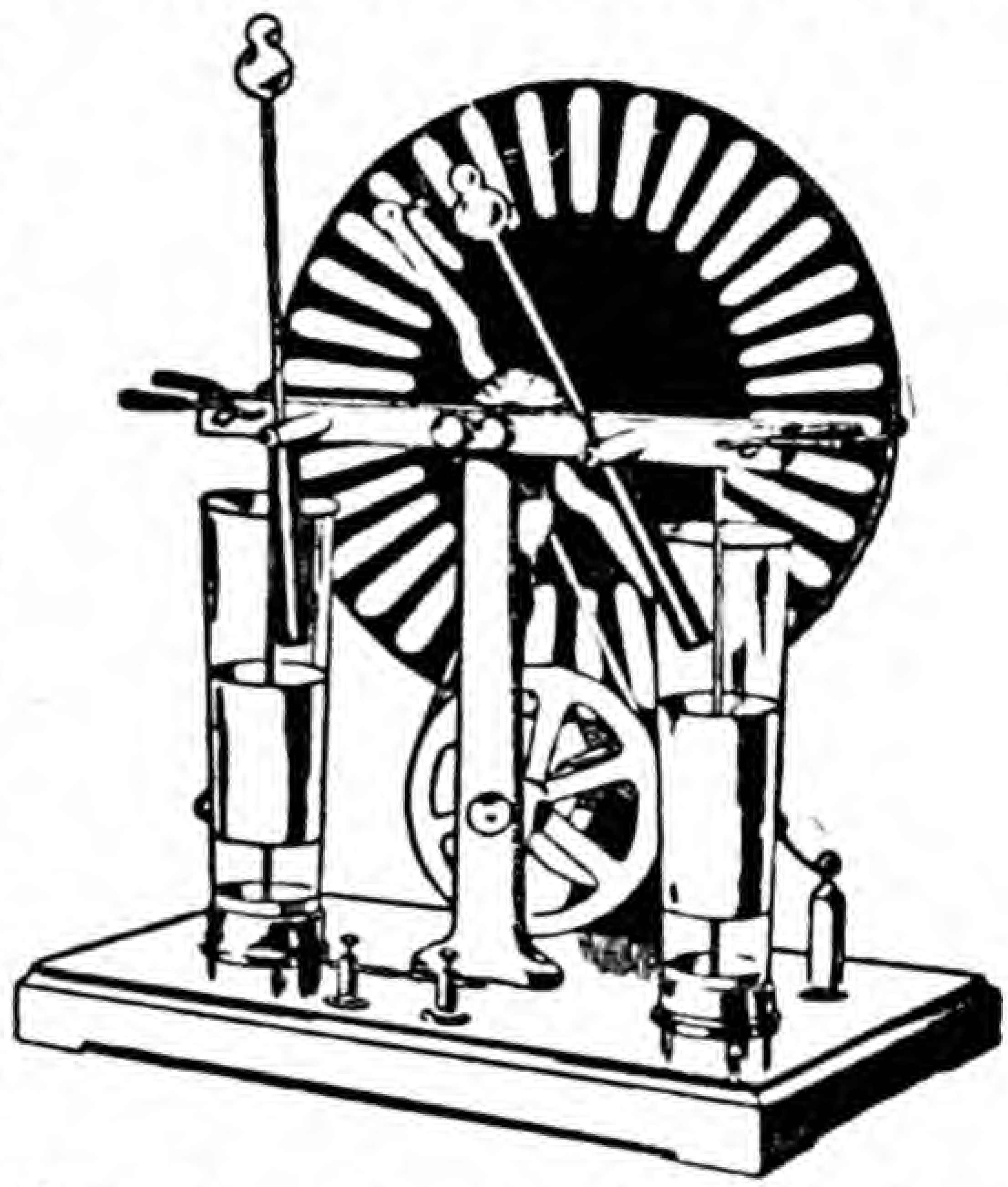


FIG. 24.—*An electrical machine.*

A matter that is very important for lightning conductors can be easily shown with such a machine. We draw the knobs apart until a spark will just not pass, and note the distance of the nearest parts. We then unscrew one knob, and fix in its place a sharp point; or else a sharp point, say a needle, may be fastened to one knob by wire. It will be found that a long spark can no longer be obtained, and if the machine is in the dark it will be seen

that a blue glow surrounds the point. This is due to the fact that electricity escapes very easily from a sharp point, much more easily than from a smooth surface. If a bit of ordinary cotton-covered wire is fastened to one ball of the machine it will be seen in the dark that the whole wire is surrounded by a glow, due to the discharge of electricity from every little point of cotton.

We can now consider lightning a little further. The thunder cloud, which looks so heavy and black in a storm,

FIG. 25.—*A thundercloud, and the charge which it induces on the earth and houses.*

may be charged with either positive or negative electricity, although negative is the commoner. If there is a negative cloud and a positive one near it, a flash will pass from cloud to cloud, just as the spark passes from knob to knob of the machine. Now suppose a positive cloud above the earth, as shown in Fig. 25. It will induce a negative charge on the earth, and eventually a spark, or flash of lightning, will pass. If there is a sharp point on the earth, however, the electricity will escape rapidly from

it, so that it is difficult for a heavy charge to gather and the spark will not be nearly as likely to pass. Such a point is always fixed to a lightning conductor. If the electricity does not escape fast enough, and the flash does pass, it will go to the point, and run down the metal strip without damaging the building. A solitary tree acts somewhat in the same way, but as there is no metal here the flash passes down the tree itself and often splits it. It is also liable to jump to any upright object near by, which is why it is so dangerous to shelter under a lone tree in a storm.

Electric charges, such as are produced by rubbing, are not so familiar to most people as electric currents, and so their behaviour may not seem so interesting. However, as we have seen, it is very important, both in pure science and in nature. We shall see in the next chapter that such charges and current electricity are very closely connected.

CHAPTER II

CURRENT ELECTRICITY

Heating Effect of Current Electricity—Magnetic Effect of Current Electricity—The Galvanometer—Chemical Effect of an Electric Current. Electric Cells—Electrical Resistance—Electrical Potential. Electrical Units—The Supply of Electrical Power—Frictional Electricity and Current Electricity are the Same Electricity

HEATING EFFECT OF CURRENT ELECTRICITY

IF we take an accumulator cell, or any other form of electric cell, such as is described later on in this chapter, and connect the two terminals with a metal wire, which, as we know, conducts electricity, then a current is said to flow through the wire. We can, however, see nothing flowing, nor can we see any change at all in the wire itself.[1] If it is, for instance, a bright copper wire, it remains a bright copper wire of the same size and shape, however long the current flows. The wire is not used up in any way. How, then, can we tell that a current is flowing, or, to put the question another way, how does a wire in which a current is flowing differ from an ordinary wire?

Let us first think of some of the effects which a current produces around us in our daily lives. Flowing through

[1] Unless, of course, the current is so heavy that the wire becomes red-hot. It should be noted that the terminals of an accumulator cell of ordinary size (say 30 ampere hours) should never be connected with a wire or other apparatus of which the total resistance is less than, say, one-third of an ohm, since taking too large a current from it damages the cell

an electric lamp it produces light. The ordinary electric lamp is merely a fine wire in a glass bulb: in one kind, the vacuum lamp, all the air has been pumped out, so that the bulb is quite empty; in another kind, the gas-filled lamp. a special gas is shut in the bulb, instead of air. This is done because a very hot wire soon burns out if the air can get at it. The two ends of the wire are connected to two pieces of metal in the base of the lamp, which are separated by insulating stuff, and press against

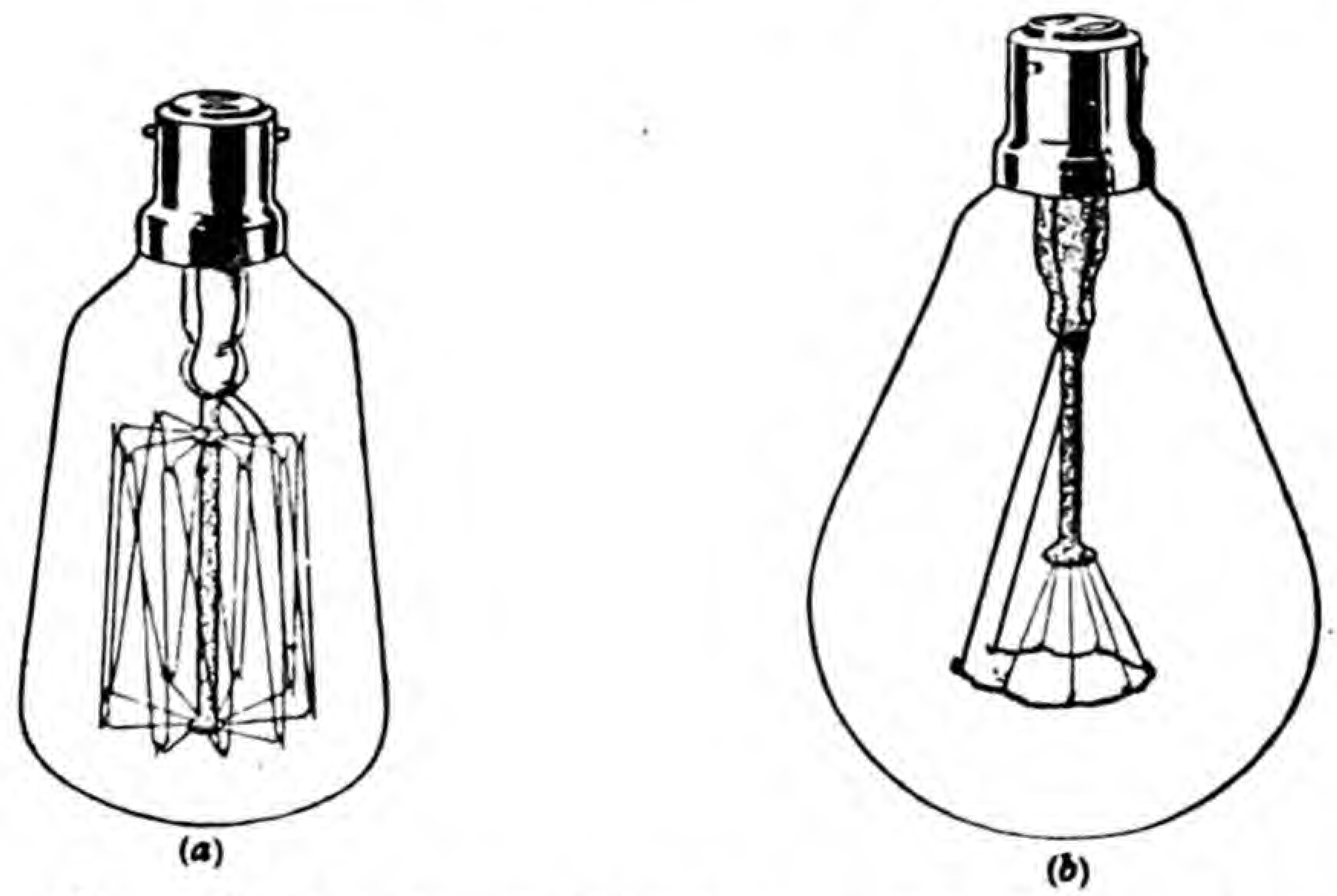


FIG. 26.—*Electric lamps: (a) vacuum lamp; (b) gas-filled lamp*

spring contacts when the lamp is pushed into its holder. The two contacts are connected to the two wires from the electric mains. When the switch is closed the current flowing through the fine wire makes it red-hot, or rather white-hot, and it gives out light. The electric lamp is, then, an example of heating produced by the current: the same light would come from a hot wire if it could be heated to the same temperature in any other way. A white-hot bar of iron, for instance, gives out quite

a good light, by which print may be read in a dark room.

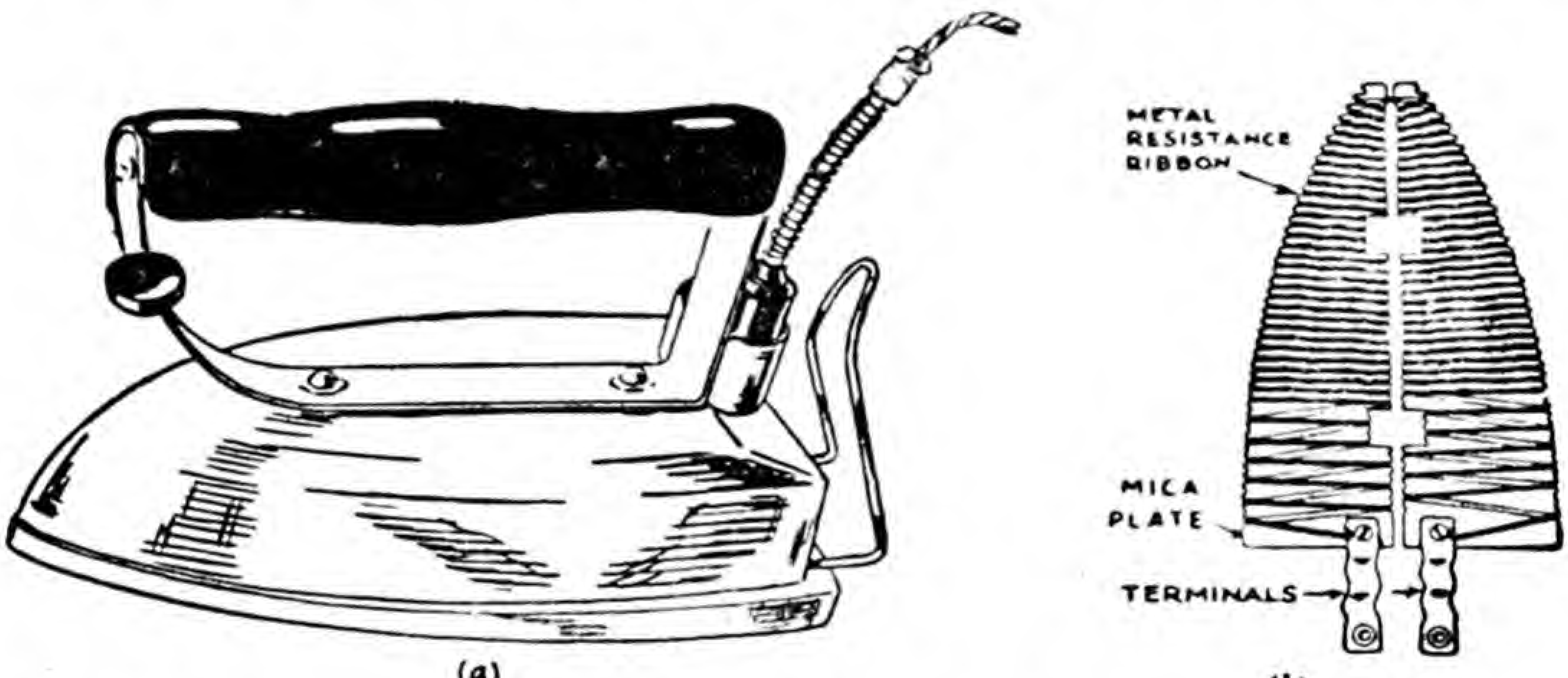
The electric radiator is also an example of a wire heated by the passage of a current, only in this case the wire is thicker, and the passage of the current does not make it so hot. It glows a dull red. The wires are usually coiled, and supported in an insulating frame. Just as the lamp gives out heat as well as light, the radiator gives out light as well as heat. The proportion of light to heat is greater the hotter we make the wire, so that in a lamp we make the wire as hot as is possible, without it melting or wasting away. Even in the best electric lamp, however, we do not manage to get more than 10 per cent. of the energy as light, the rest being wasted as heat.[1] In the electric radiator, since we do not want light from it, we arrange for the wire to be at a much lower temperature than the lamp wire, and so to glow a dull red, instead of white-hot. The lamp wire has to be shut up in a glass bulb, as we have said, to prevent the air from attacking it, for the oxygen in the air acts upon a *very* hot wire, whatever metal it is made of. There are, however, plenty of alloys suitable for making electric radiators which can be raised to a dull red without suffering from any action of the air.

FIG. 27.—*An electric radiator.*

[1] We say "wasted" because we do not require heat from an electric lamp. In the electric radiator, however, this heat is just what we want.

An electric iron is another common example of electrical heating. It contains a long strip or ribbon of metal, wound on mica, which is a good insulator, and the passage of the current through the metal raises the temperature of the whole iron.

We see, then, that one effect which a current can produce in a wire is heat, yet the wire connecting the terminals of our accumulator to other electrical apparatus does not get red-hot, and neither do the wires which lead the current to an electric lamp. Does this mean that



(a) (b)

FIG. 28.—*An electric iron: (a) outside view; (b) the heating ribbon inside it.*

sometimes the current produces heat, and sometimes does not? No, it only means that in some cases the heating effect is smaller than in others and is often not enough to be felt with the fingers, let alone to produce a visible glow. We can easily show that the wire conveying the current from the accumulator produces heat. Let us take a piece of wire covered with insulating varnish, and twist it into a coil of many turns, or make a coil of bright copper wire, and then varnish it carefully. Place the coil in a beaker of water, with a thermometer down the centre, and connect

the ends to the terminals of the accumulator. The temperature of the water will be seen to rise steadily.

The little so-called pea lamps that are used in pocket torches contain a very fine bit of wire, so thin that the small current from the dry cell in the holder will be sufficient to raise it to white heat, so that it gives out light.

One general effect of a current is, then, that it heats any wire in which it is flowing. If there are two similar

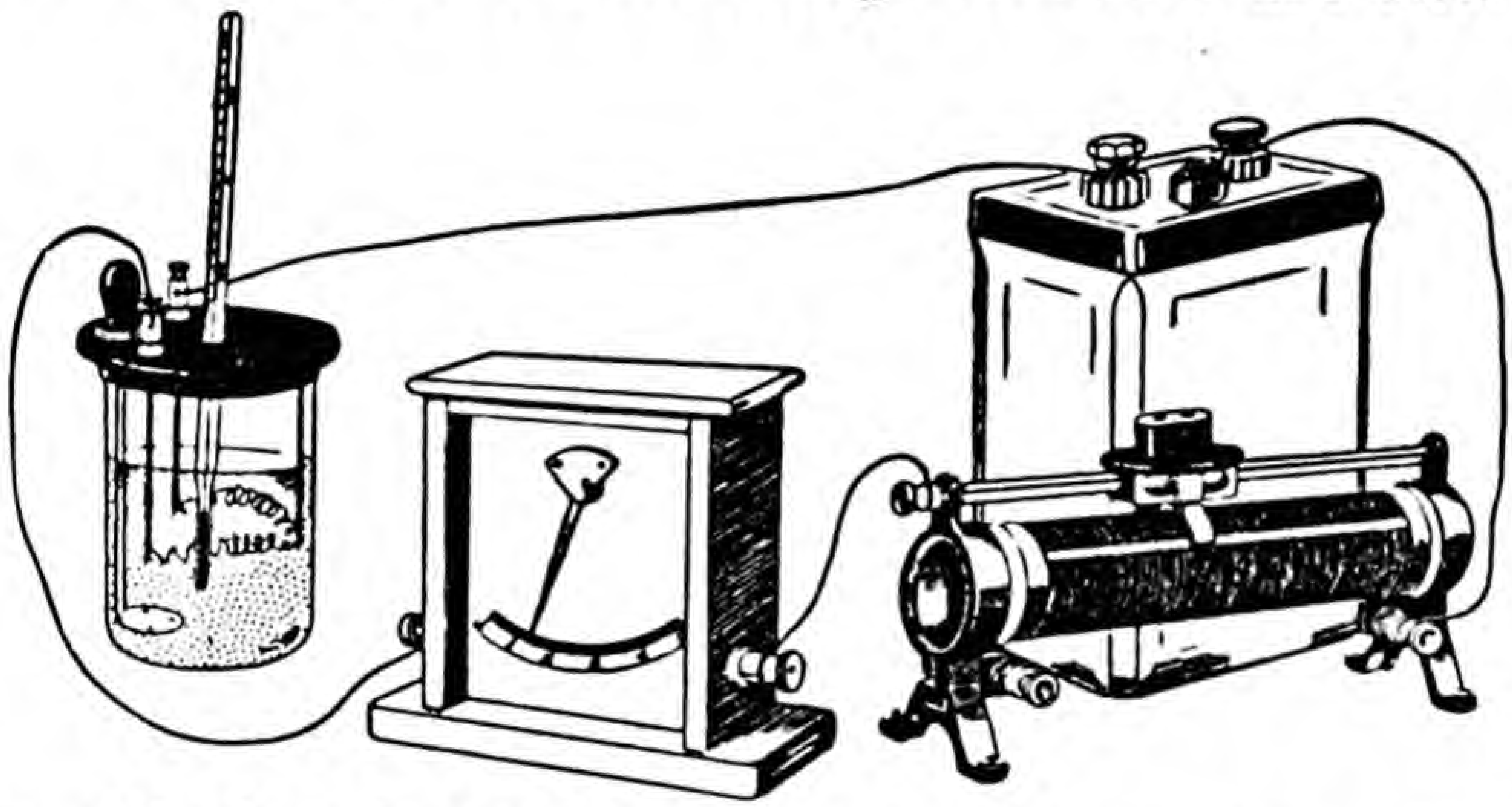


FIG. 29.—*To show the heating produced by a current. The coil of wire in the beaker on the left is heated by the current from the accumulator, which flows through a rheostat and an ammeter, to control and to measure the current.*

wires side by side, one carrying a current and one not, the one carrying the current will be warmer, however small the current, but if the current is very small the heating effect will be difficult to notice and to measure.

MAGNETIC EFFECT OF CURRENT ELECTRICITY

Let us now turn to another extremely important effect which a current can produce. We take a rod of what is called "soft" iron,[1] and prove that it is not a magnet by

[1] Soft iron is pure iron, without carbon in it.

trying in vain to pick up iron filings with it. We now wind insulated copper wire on it,[1] and join the ends of the wire to the terminals of our accumulator. The iron becomes a strong magnet as soon as the current flows: it picks up filings, or supports a second rod of soft iron equal in size to itself. As soon as one wire is undone the iron ceases to be a magnet. With certain kinds of iron a feeble magnetism remains after the current is cut off, so that the iron will pick up a few filings, but this residual, or remaining, magnetism, as it is called, is very much less than that when the current is flowing. With steel, however, the residual magnetism is quite large, and we can make a steel rod into a permanent magnet in this way.

When various wires are joined up so that a current flows through them the wires are spoken of as forming a circuit; when we disconnect one of the wires so that the current no longer flows we are said to "break the circuit." In this way of speaking, then, we say that as long as the circuit is complete the soft iron rod is a magnet; when the circuit is broken, all, or nearly all, of the magnetism disappears.

If we bring an ordinary steel magnet (which, since it always remains magnetic, is called a permanent magnet) near the soft iron, the iron becomes magnetic. We may, for instance, fix the soft iron upright just above a paper strewn with filings; when we bring the permanent magnet above it, as shown in the picture, the iron attracts the filings. We say that the magnetic power of the magnet

[1] A rod about 3 inches long and $\frac{5}{16}$ inch in diameter, wound with about 500 turns of No. 22 S.W.G. ("Standard Wire Gauge," used for measuring the diameters of wires) cotton-covered wire in layers is suitable for the experiment. It is well to put a rheostat in the circuit, to control the current, and an ammeter to measure the current (see pp. 48, 58).

has made the soft iron magnetic. We have seen that a current flowing round it has the same effect on soft iron. It looks, then, as if a current produced a magnetic force at points near it, just as a permanent magnet does.

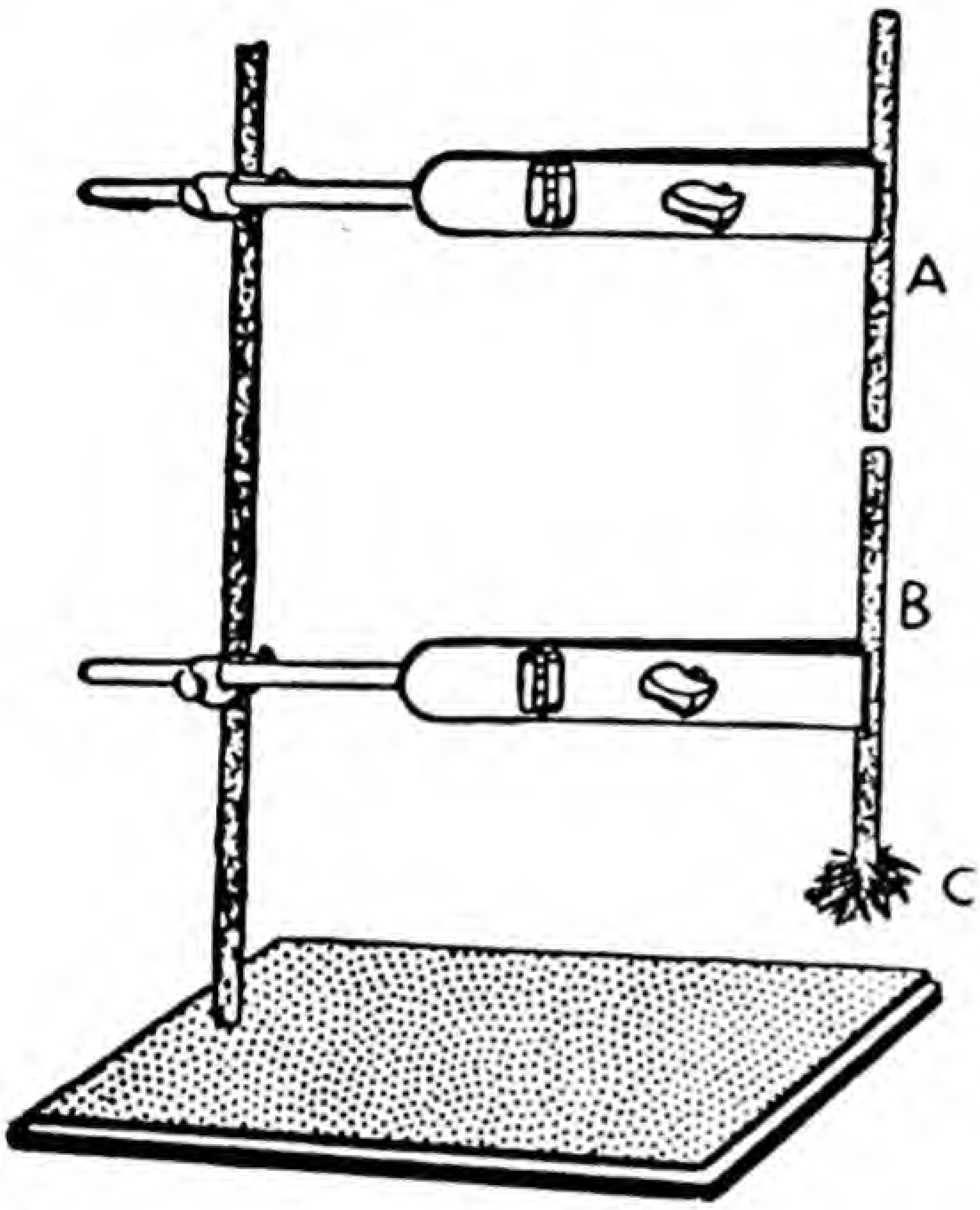


FIG. 30.—*A permanent magnet (A) makes a soft iron bar (B) near it into a magnet, as shown by the attraction of the iron filings (C).*

A very good way to show that there really is a magnetic force in the neighbourhood of a current is to use a delicately pivoted little magnet, which turns easily, such as is used in a compass. Any magnetic force across the length of the magnet will make it turn so as to point in a new direction, as we can easily show with the permanent magnet. If, now, we wind on a piece of brass tube, or on a wooden rod, about the same size as the previous iron rod, several turns of copper wire, and connect to a cell as before, we shall find that the end of this coil will act on the pivoted needle just as a magnet does, although we may have to put the end fairly close to show this. The current alone, then, produces a magnetic force. If we slide an iron rod into the brass tube, the magnetic force turns it into a magnet, which affects the pivoted needle very much more strongly than the current alone.

The current produces, then, a magnetic force at points near the wire through which it is flowing. It is not necessary to coil the wire to show this. We can join the

terminals of our accumulator with a piece of copper wire, and bring the wire very close to the pivoted magnet, so as to lie along it and just over it.[1] The magnet will turn in one direction. If, keeping the wire just over the magnet, we disconnect the ends, and rejoin to the reverse terminals, so that the current flows in the other direction over the magnet, the magnet turns in the reverse direction. If, leaving the poles as they are, we put the wire under the magnet, instead of over it, the direction in which the magnet turns reverses again.

With a single wire parallel to the magnet, then, the direction in which the magnet moves depends upon, firstly, the direction in which the current flows and, secondly, whether the wire is above or below the magnet. With the wire above, and the current in a given direction, the direction of movement of the magnet is the same as with the wire below, and with the current in the reverse direction, for we have changed the direction of movement of the magnet twice, so that it is back where it was.

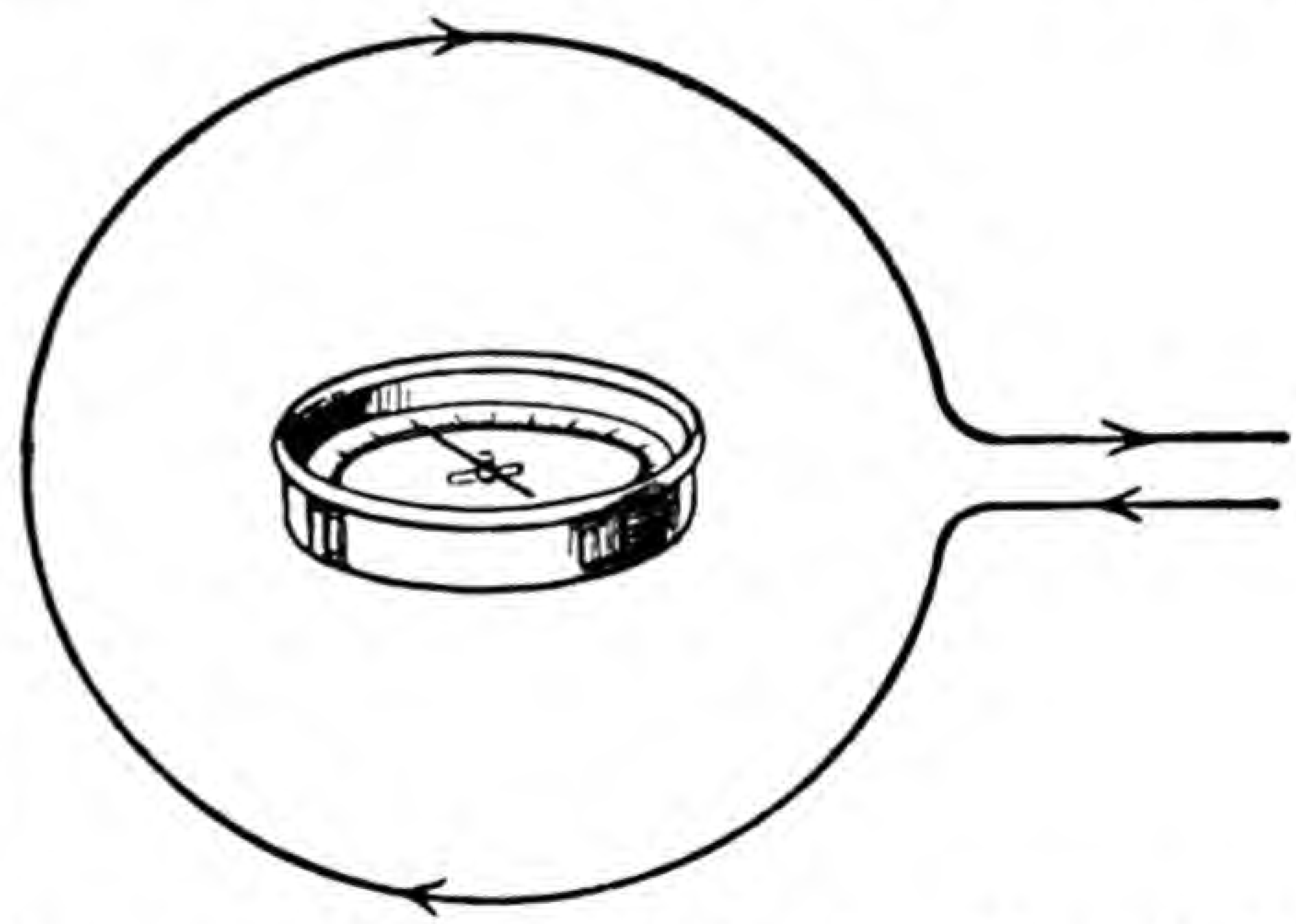


FIG. 31.—*The current flowing through the upper part of the coil turns the magnet in the same direction as does the current flowing through the lower part of the coil.*

Now consider the ring of wire round the magnet in Fig. 31. Above, the current is flowing from left to right;

[1] Again, it is best to put a rheostat and an ammeter in the circuit, to make sure that too big a current is not taken from the accumulator. About 4 amperes will produce a good effect.

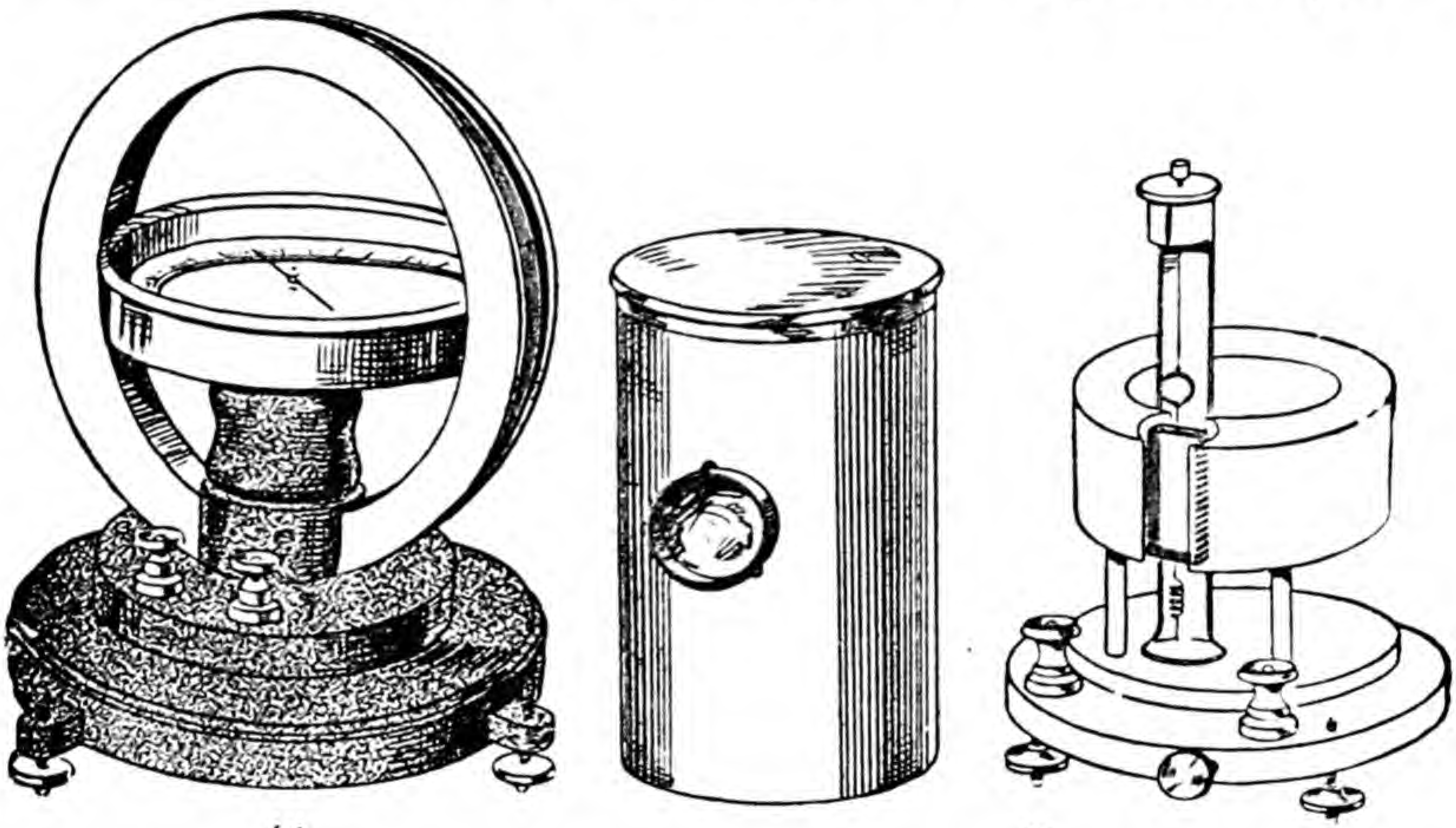
below, from right to left. Both the upper and lower parts of the ring help to turn the magnet in the same direction, so that a turn of wire right round the magnet produces a bigger effect than a straight wire above the magnet. If we have several turns the effect will, of course, be much stronger than that with one turn.

There is a simple rule which tells us in which direction the magnet will move. When the positive pole of a battery is connected to the negative the current is said to flow in the wire from the positive to the negative pole. Now suppose that you are swimming with the current, and facing the magnetic needle—that is, you are swimming on your face if the wire is above the needle, and on your back if the wire is below the needle. Then the north pole of the magnet will be moved to your left hand by the current, and the south pole, of course, in the opposite direction.

The Galvanometer

We can now consider how an instrument can be made which will show and measure electric current. Such an instrument is called a galvanometer. A small magnet is pivoted at the centre of a card marked in a scale of degrees. To the magnet is fixed a light pointer reaching to the scale, and the whole thing, magnet and scale, is usually contained in a shallow box covered with glass, to prevent draughts disturbing it. This box is fixed at the centre of a wooden or metal hoop arranged vertically, on which are wound several turns of insulated wire, the ends being fastened to terminals. The instrument is usually provided with screw feet, by which it can be levelled (Fig. 32*a*). The whole instrument should be set on the table so that the

ends of the magnet itself point at the middle of the sides of the hoop. If now a current is made to pass through the wire, by joining a cell to the terminals, the magnet will turn through an angle: the larger the current the larger the angle. This does not mean that twice the angle shows that twice the current is passing: actually, doubling the



(a) (b)

FIG. 32.—*Galvanometers: (a) a moving magnet galvanometer; (b) a moving coil galvanometer. The strong magnet is made in a ring shape, and the coil hangs in the gap between the two poles. To the left of the instrument stands the case which is put over it to protect it from draughts.*

current produces a movement through something less than twice the angle. There is a law connecting the angle with the current, but it needs more mathematics to express it than most of the readers of this book have yet reached, and we will leave it aside. In many instruments the current is marked instead of degrees; when this is done the divisions of the scale will not be equal.

There are many different kinds of instrument made on this principle to measure current. In very delicate ones, to measure very small currents, the magnet is hung up on a very thin thread or wire, instead of pivoted, for a properly hung magnet turns easier than one on a pivot. In other instruments the magnet and coil are shut up in a little case, so that only a pointer shows. This pointer reads on a scale which is marked not in degrees, but in the current: that is, the marks of the scale are labelled, say, 1 ampere, 2 amperes, 3 amperes, and so on, for, as we shall see later, currents are measured in a unit called amperes, just as lengths can be measured in yards, and weights in pounds. Such an instrument, which measures currents, is called an ammeter, short for amperemeter. In other very simple instruments there is a magnet which is used chiefly to show whether any current is flowing or not; the men who repair telephone wires use this kind of thing (Fig. 33).

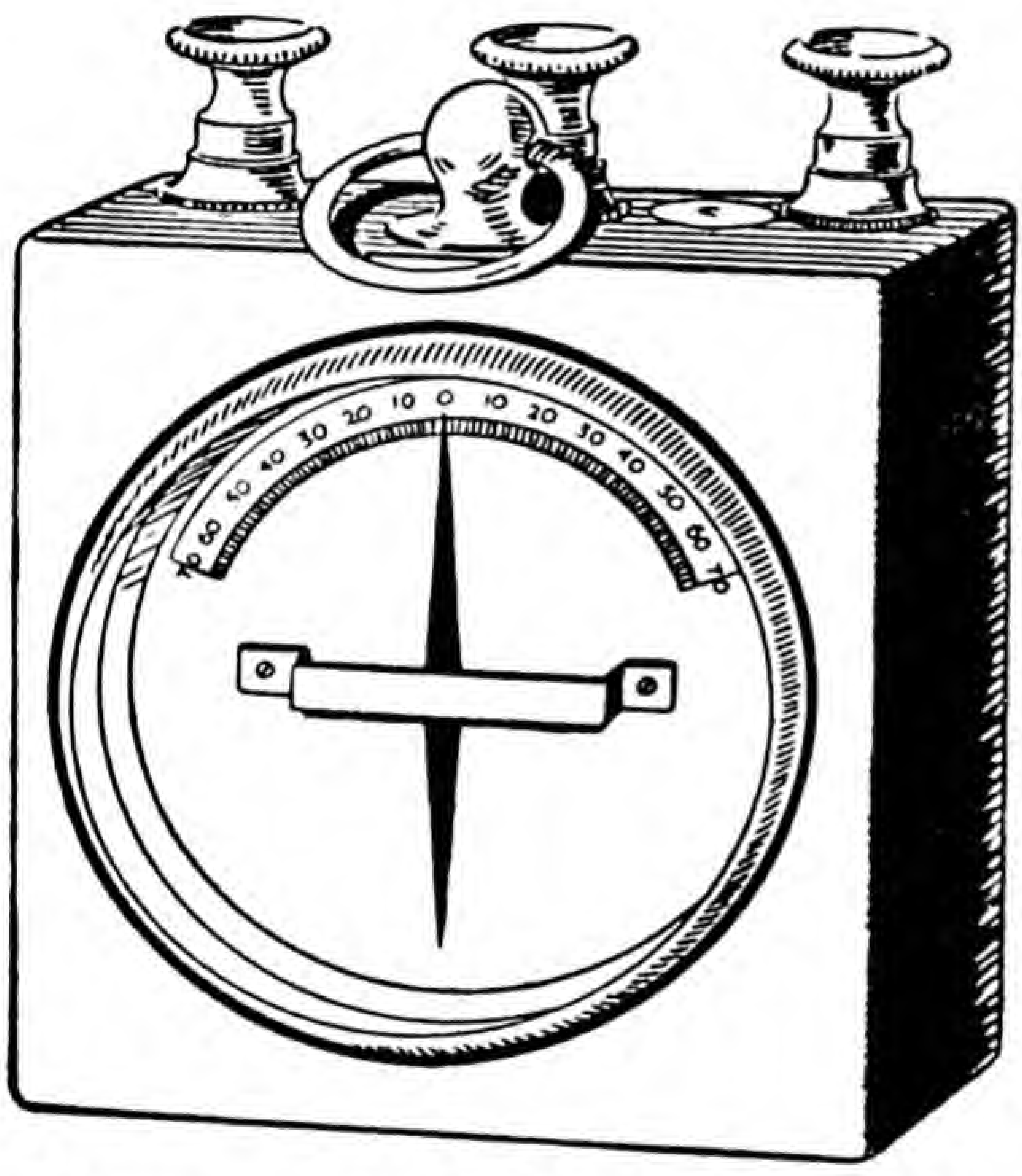


FIG. 33.—*A simple galvanometer: a telephone linesman's instrument.*

In some ammeters a little coil of wire is hung up between the poles of a strong magnet, as shown in Fig. 32*b*. When a current passes through the coil it behaves, as we now know, like a magnet, and so is turned aside by the strong magnet, twisting the fine wire by

which it is hung. The bigger the current through it, the farther it will turn, for the more it can twist the wire. The amount of turn is often measured in the following way: a small light mirror, no bigger than a threepenny bit, often much smaller, is fastened to the coil. A beam of light from a lamp falls on this mirror, and when the mirror turns the beam of light turns too. The movement can be seen on a glass strip on which the light falls. If this strip is a yard off from the mirror the light is as good as a pointer a yard long, but it weighs nothing.[1]

Chemical Effect of an Electric Current. Electric Cells

In Book I we saw that when an electric battery is joined to two pieces of platinum dipping into water, the water is broken up into the gases oxygen and hydrogen. If we now put a galvanometer in the circuit we can show that a current is passing through the water. If we were to put some more cells in the circuit (if, for instance, we use six large dry cells first of all, and later try the experiment with three more cells) we should find that two things happened, first that the gases came off faster, and second that the current became larger. This tells us that it is the current which breaks up the water, and that the larger the current which passes the quicker the water is broken up. This splitting of water into the gases of which it is composed, or decomposition of water as it is called, is an example of one more effect

[1] Actually the beam of light is better than the pointer, for if the little coil turns through an angle of $5°$ a pointer would turn through the same angle of $5°$, but the beam of light turns through double the angle, that is, through $10°$, as can easily be seen by considering the laws of the reflection of light, given in Chapter IV.

of the electric current, the chemical effect. Whenever a current passes through a liquid some chemical change takes place. Certain liquids, however, such as oils, will not allow the current to pass: they are insulators. If two metal plates are placed in oil, and joined up to a cell and a galvanometer, the pointer of the galvanometer will not show the least movement. The oil remains absolutely unchanged. The chemical effect and the current go together: no current, no effect.

A clear liquid may have a chemical compound of a metal dissolved in it, such as blue copper sulphate, of which we have spoken in Book I. To the eye there are no signs of the metal: the liquid may be blue or it may be colourless, according to the chemical which it contains, but nothing can be seen floating in it. If two metal plates are put in the solution, however, and an electric current is made to pass from one to the other, it will carry the metal out and deposit it on one of the plates. This chemical process is called electro-plating, and coats of gold, silver, copper, nickel, chromium, and other metals are put on to metal objects by this method, as already mentioned in Chapter I. All nickel-plated bicycle parts, for instance, are results of the chemical action of electricity.

Copper is particularly easy to plate. Suppose, for instance, that we want to make a copper copy of one side of a coin or medal. The object is pressed hard into a block of wax, so as to produce a good impression of the head or whatever pattern is on it. This impression is then brushed all over with graphite, which conducts electricity, and a wire twisted round the wax so as to touch the graphite coating. Some crystals of copper sulphate are then dissolved in water, and in the beautiful clear blue liquid the wax mould is placed,

facing a copper plate. The positive pole of a battery is connected to the copper plate, the negative to the wax mould. If things are left like this for a few days a thick coat of copper will be found to have formed on the parts of the wax rubbed with graphite, and if the wax mould is broken from the copper a good copy of the medal in copper will be found. The picture in Fig. 34 shows ordinary electro-plating going on. The tank contains a solution of silver, with which a spoon, knife and fork are being covered.

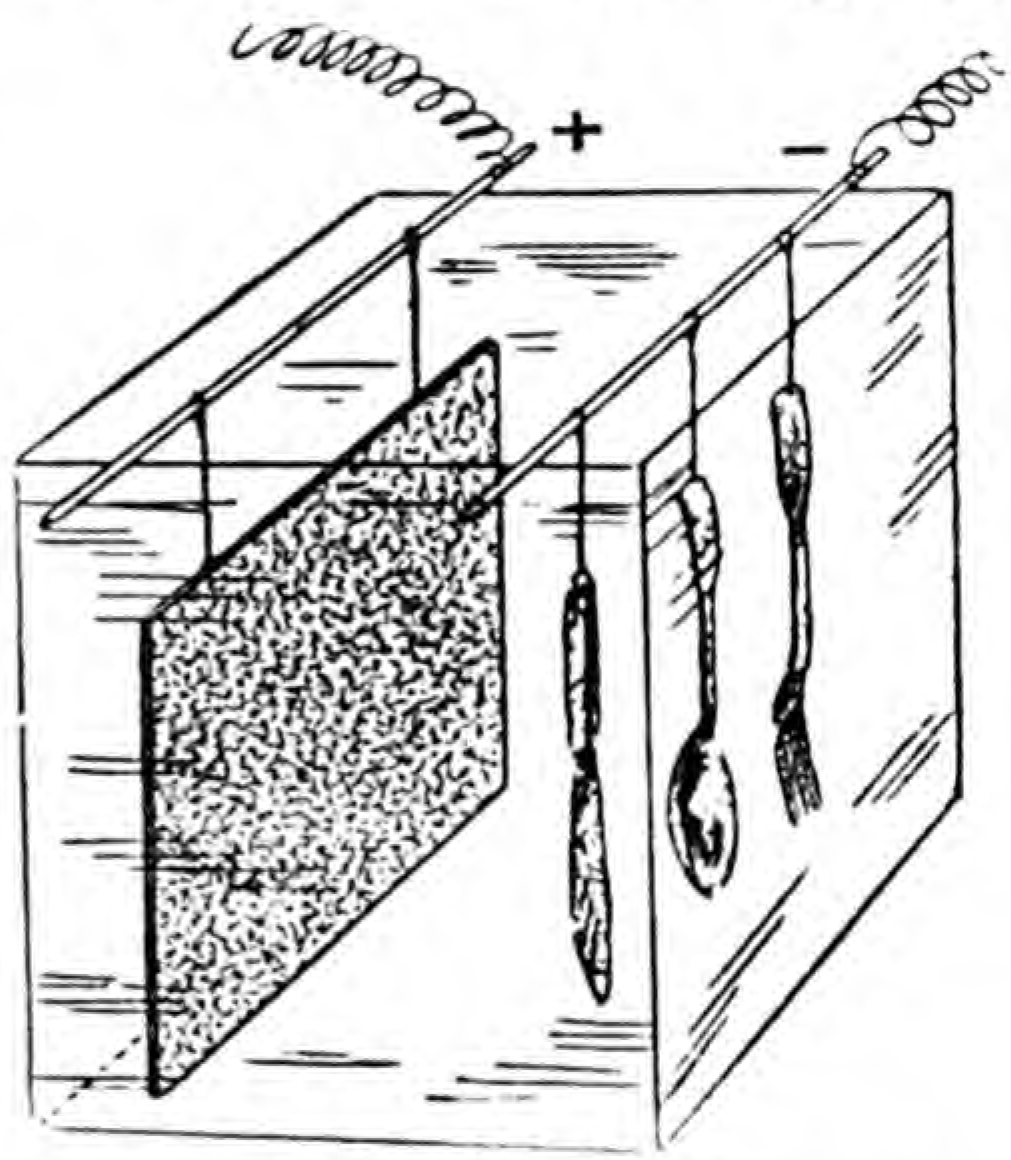


FIG. 34.—*Electro-plating.*

Pure metals can be separated from their compounds in this way. How electricity is used to make aluminium from bauxite (see p. 43) is described in Chapter V.

Electricity, then, produces certain chemical effects. The reverse is also true—certain chemical effects produce electricity. This fact is used in the electric cells which give an electric current. Let us consider a type of electric cell, not much used nowadays, invented by Daniell and called after him (Fig. 35*a*). It consists of a copper pot containing some of the blue solution of copper sulphate which we have just mentioned; in this stands a pot of unglazed pottery, called a porous pot, because it contains an immense number of very fine passages, or pores, through which liquid can slowly pass. The porous pot holds weak sulphuric acid with a zinc rod in it. If the zinc rod be joined to the copper pot through a circuit a current

flows, but if the circuit be left joined up for a few days the zinc rod will be badly eaten away, and the blue solution will have become very weak. If, however, the zinc rod and copper pot are not connected, nothing of this kind happens if the zinc rod is perfectly pure.[1] That is, if a current is obtained from the cell, chemical action takes place in the cell, but if no current is taken, then there is no chemical action. Once more we see that the two go together. In the old days people used to think

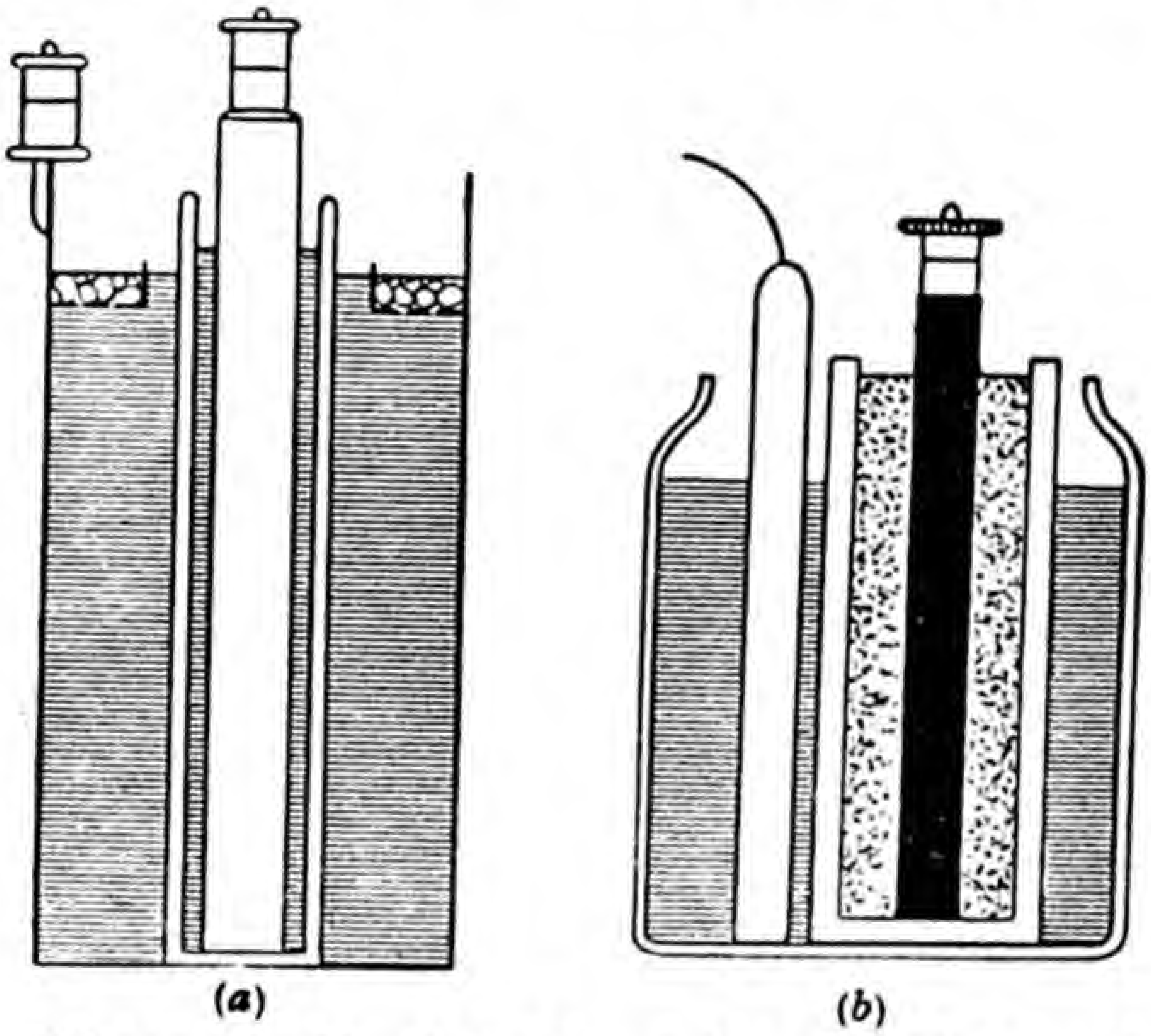


FIG. 35.—*Electric cells: (a) Daniell cell; (b) Leclanché cell.*

that, if the cell was made carefully enough, they would get current from it for ever, and that it was just chance that the materials of the cell were used up, just as it is by chance that the wheels of a car may rust, and nothing really to do with the going of the car. They hoped in this

[1] Between the weak sulphuric acid and the impure zinc supplied in the ordinary way there is, however, a chemical action. To get over this the zinc is usually rubbed with mercury, which sticks to it, forming a kind of surface compound. The zinc is then said to be *amalgamated*, and withstands the action of the acid when no current is flowing.

way to get a perpetual motion. We know nowadays, however, that we cannot get electrical energy from nothing. Just as in a furnace coal is burnt to get heat, so in the cell chemicals are used up to get electricity.

Another kind of cell, often used for electric bells, is the Leclanché type (Fig. 35*b*). It depends, of course, on chemical action, like all other cells. Instead of the copper plate, which is the positive in the Daniell cell, we have a plate of carbon, the negative being a plate of zinc or a rod of zinc. The carbon plate is in a porous pot, and is packed tight with a mixture of black oxide of manganese and carbon, while the zinc rod stands in a solution of sal-ammoniac, which is a chemical more properly called ammonium chloride. This cell is particularly mentioned because the dry cells used so commonly in pocket torches and elsewhere are made on these lines. To avoid spilling, however, the liquid sal-ammoniac is replaced by a paste of sawdust and glycerine moistened with a strong solution of sal-ammoniac. If this sawdust paste were not damp, if it were really "dry," the cell would not work; the word "dry" means that there is no free liquid which will run out. As current is taken from the cell the zinc disappears, owing to chemical action, and in the end wears through, and the cell is finished. As long as the cell is not being used the zinc does not "wear out."

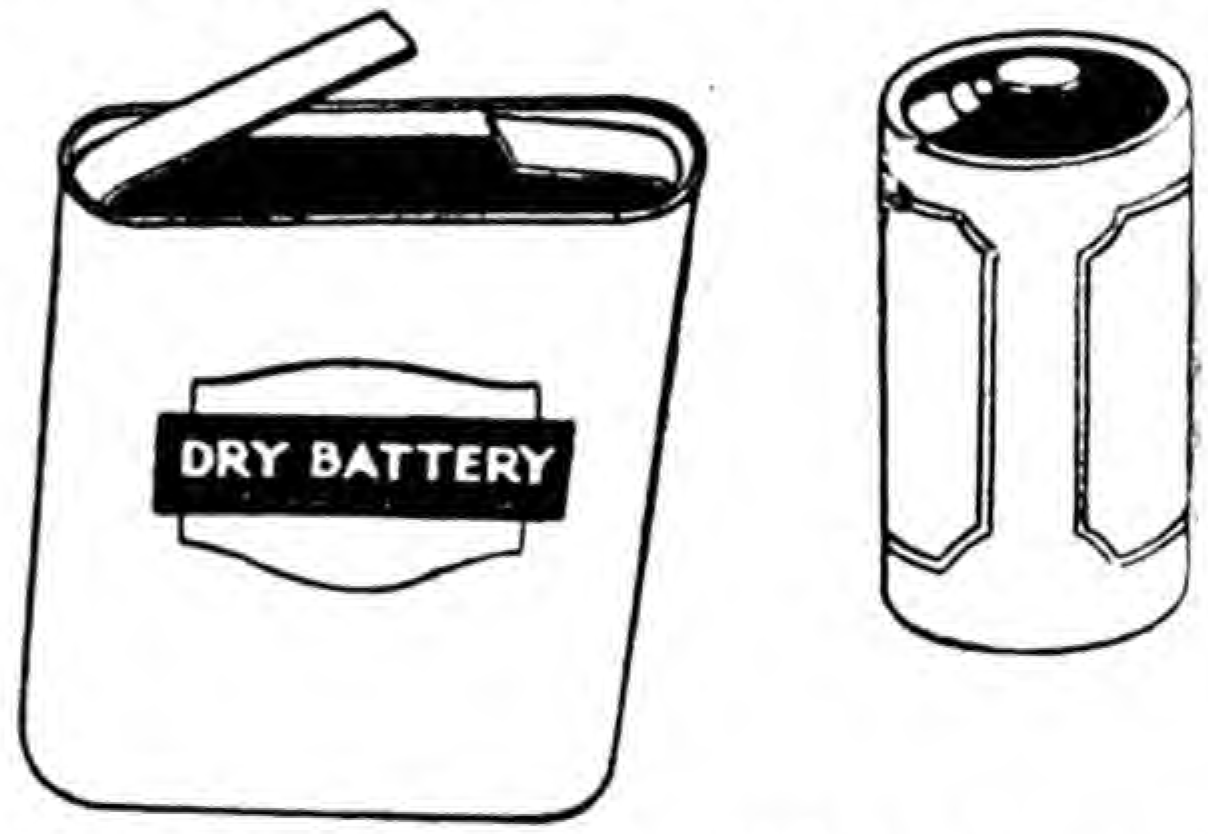


FIG. 36.—*Dry cells. They are made on the same lines as Leclanché cells, but the liquid is made into a paste with sawdust and glycerine.*

We see, then, that a current can produce a chemical

change, and a chemical change can produce a current, and that in both cases if no current passes nothing happens chemically. A natural question to ask is whether, when a cell has run down owing to the chemical change being completed, we cannot make the chemical change go backwards by passing current into it in the reverse direction, and thus get the cell back as it was before we originally started to take current out of it. The answer is that there is a very important kind of cell that has this property, that after current has been taken out of it in one direction, with chemical change, the chemicals can be put back to the same condition as before by making a current run through the cell in the other direction. Such cells are called accumulators, and when we run a current through them backwards we are said to be recharging them. The cell is in some ways like a spring which runs down, turning a wheel, say, in one direction: we can wind the spring up again by turning the wheel in the reverse direction.

A simple accumulator consists of two plates standing in sulphuric acid. When the cell is fully charged and ready for work, the positive plate, which appears chocolate in colour, is of lead oxide (a combination of lead and oxygen), packed into a hard lead frame, while the negative plate is spongy, bluey-grey lead, likewise held in a hard lead frame. As the cell is used, both plates combine slowly with the sulphuric acid, and become alike, turning whity-grey in colour owing to the formation of the chemical known as lead sulphate. When the cell is charged again, by passing a current through it in the reverse direction to that which comes out of it, the positive plate becomes chocolate-coloured again, and the negative bluey-grey. The accumulator, then, is a very good example of the way in which current and chemical

change go together. Every time that we charge it we put in electrical energy and build up certain chemical compounds; every time that we use the accumulator we take electrical energy from it, which is set free by the chemical compounds breaking up. When the accumulator is standing charged, with the terminals not connected, no electrical energy is being taken from it and there is no chemical action going on.

There is one sign of the chemical action which is of great use in the care of accumulators. The liquid in an accumulator is a mixture of concentrated (that is, very strong) sulphuric acid and water. Concentrated sulphuric acid has a density of 1·84 grams per cubic centimetre, while the density of water is 1 gram per cubic centimetre. We may also say, which comes to the same thing, that the *specific gravity* of concentrated sulphuric acid is 1·84, for the specific gravity of a substance is the weight of a given volume of that substance divided by the weight of the same volume of water, or, in other words, the specific gravity tells us how much denser a given substance is than water.[1] The right density of the diluted sulphuric acid solution in the charged cell should be about 1·250 grams per cubic centimetre. But during discharge sulphuric acid is taken from the solution and combined

[1] See also Book I, p. 141. It should be noted that as specific gravity is a comparison with water, the units do not come in, for if we take the weight of 1 cubic inch of iron to compare with the weight of 1 cubic inch of water it gives just the same result as if we take 1 cubic centimetre of each, and since the weights are merely compared it does not matter what they are measured in, either. But density is the weight of a piece of given size, and therefore we must give the units of weight and of size. As, however, 1 cubic centimetre of water weighs 1 gram, the density *in grams per cubic centimetre* is the same figure as the specific gravity. Think it out.

with the lead, which makes the solution weaker, and so less dense. When the cell is run down, the density will be found to be only about 1·10, and it should never be allowed to become less. It will go up again when the cell is recharged. The density is most easily found with a hydrometer[1] specially made so as to measure densities between 1·3 and 1·1.

Electrical Resistance

If an accumulator cell is connected to a galvanometer, or, better still, to an ammeter, it will be found that the reading of the instrument depends upon the wires in the whole circuit. It is easy to show that, if wire of one kind is used, say iron wire of about a hundredth inch in diameter, then the longer the wire the smaller the turning aside, or deflection, as it is called, of the pointer of the instrument, that is, the smaller the current. If wires of the same metal and length are taken, say copper wires 15 feet long, but of different diameters, say 42 S.W.G. (which is about 4 thousandths of an inch in diameter) and 36 S.W.G. (which is about 7 thousandths), then it will be found that the finer the wire the smaller the current. If, finally, wires of the same length and the same diameter are taken, but of different metals, it will be found that the current is different in each case. Thus, if the metals are copper, brass, and iron, the current is weakened least of all by the copper, and less by the brass than by the iron.

It does not matter in what part of the circuit a certain wire is put, whether fastened to one pole of the accumulator or to the other, or whether it is not fastened direct to the poles, but to other wires which are joined to the

[1] See Book I, p. 138.

poles. So long as the same wires are in the circuit, and so long as they are joined so that the circuit flows through one after the other, the order has no effect on the size of the current flowing.

Any extra wire put into a circuit, then, cuts down the current, although if the wire is thick and short the effect is very small. This fact is expressed by saying that the wires offer a *resistance* to the current, or that they have electrical resistance. From what we have just said the resistance depends upon the length and diameter of the wire, as well as upon the metal of which it is made. The longer the wire, for one thing, and the thinner the wire, for another, the bigger the resistance. The resistance of copper is less than that of brass, and of brass is less than that of iron. We can look at things another way, and think of the wires as conducting the currents round the circuit. We then say that copper conducts an electric current better (that is, with less loss) than brass or iron, or that copper is a very good conductor of electricity. As a matter of fact, copper conducts better than any other metal, and it is for that reason that the wires on electric mains and wirings of all kinds are made of copper.

It may be asked what becomes of the energy that seems to be lost. Supposing, for example, that we connect a battery of cells with an electric motor, then a certain current flows through the motor and we can get work done. The motor may, for instance, drive a small crane and lift weights. If to the same battery we connect up a resistance of suitable size, instead of the motor, we may have the same current flowing under the same driving force of the cells, and yet get no work done.

[1] See Book I, Chapter IV.

What happens is that the resistance wire gets hot: the energy that appears as mechanical work when the motor is used appears as heat when the resistance is put in its place.

If, then, we want a current to pass with very little loss of energy, so that we can use it at some point for some useful purpose, we lead it along by good conductors. If, however, we want it to produce heat we make it flow through conductors of high resistance. The wire in an electric lamp, for instance, is made long, and so has to be taken backwards and forwards, or coiled (see Fig. 26), and thin, so that great heat is developed. The wires in electric radiators, which have to be made fairly thick for strength, are firstly made of an alloy that has a high resistance, and secondly are very long. They are coiled closely so as not to take up too much room.

For many purposes it is convenient to have in an electric circuit a resistance that we can alter. Such a resistance is called a rheostat, as everybody who has had anything to do with a wireless set knows. A rheostat is made of a long wire with some kind of a slider which touches it, and can be moved along to any position. One end of the wire is connected to one side of the circuit, and the slider to the other side: then the current flows through the part of the wire between the end and the slider only, and the length of this part, and so its resistance, can be altered at will. The wire is usually coiled, so as to take up less room. In Fig. 37 common forms of rheostat are shown. It is usually convenient to have a rheostat of some kind in any circuit with which we are experimenting, so that the current can be changed as we like, and also an ammeter, so that we can see what that current is. If it is greater than we want we move the slider of the

rheostat so as to put more resistance in the circuit. In electrical diagrams a rheostat is usually represented as

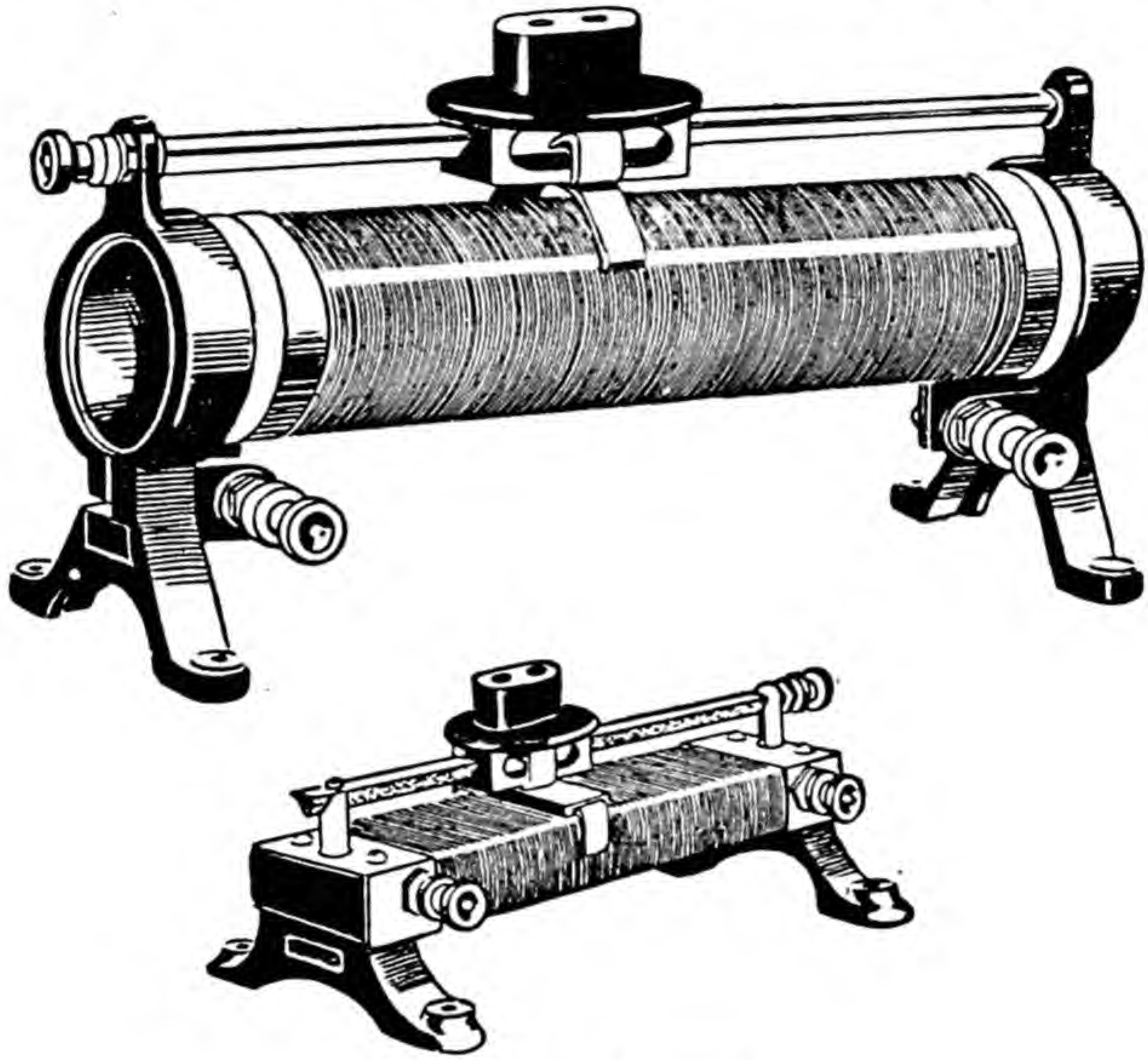


FIG. 37.—*Rheostats.*

shown in Fig. 38, where the usual symbols for a galvanometer and for an electric cell are also shown. These are a kind of shorthand picture, to save drawing the instruments as they really look. The short fat stroke is usually taken to represent the positive, and the long thin stroke the negative plate of the cell.

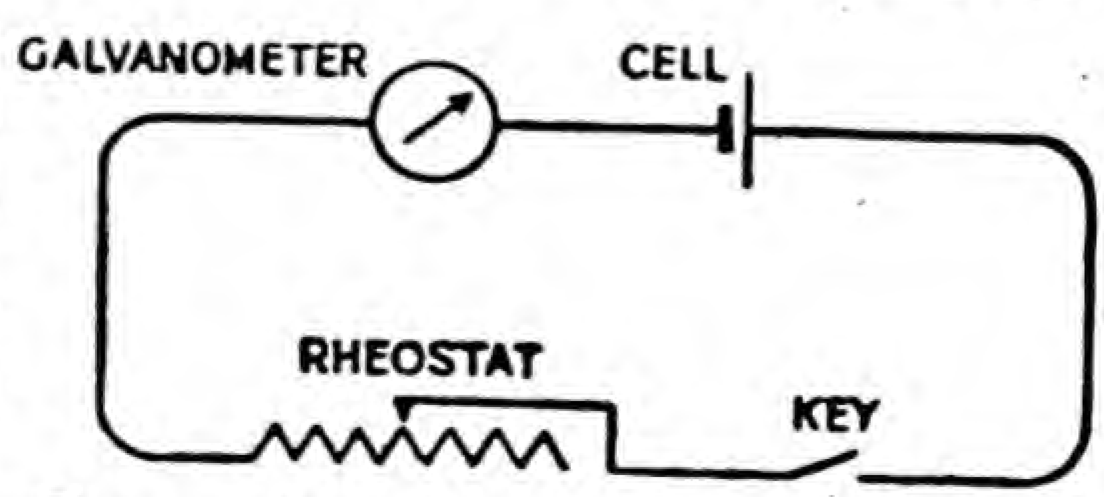


FIG. 38.—*The symbols used to represent some common electrical instruments.*

In the circuit is also put the symbol for a "key." This is a useful little device for quickly opening and closing a circuit—a picture of it is given in Fig. 39. The terminal B is connected to the little stud C by a thick copper wire running under the base, which is made of wood or ebonite. One wire of the circuit is connected to B, and the other to A.

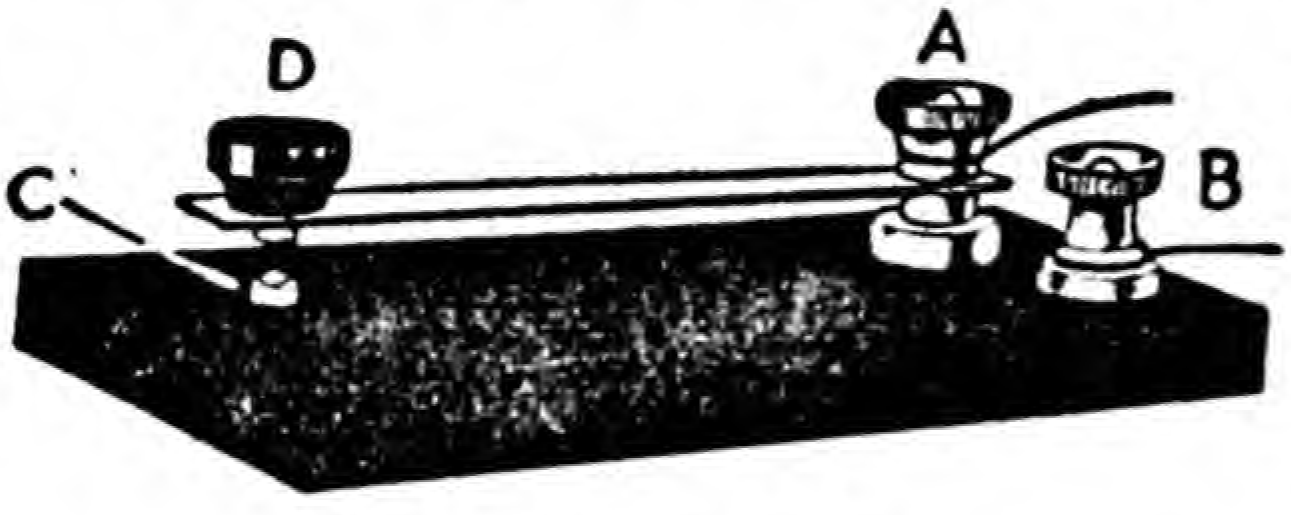


FIG. 39.—*A key.*

When the knob D is pressed down, A is connected electrically to C, and the current can flow through to B by way of the wire under the base. When the pressure is taken off, D springs up again, and the circuit is broken.

ELECTRICAL POTENTIAL. ELECTRICAL UNITS

We can get a clearer idea of an electrical circuit if we consider the more familiar flow of water in pipes. We can think of a water circuit made up of a tank and a cistern at a higher level, joined by various pipes, and we can include in the circuit a water meter, which tells us how much water flows through every minute, and a water turbine, which is worked by the current of water. To keep the water in the cistern we must have a little pump, which can raise the water 10 feet, say, but is not strong enough to raise it higher.

The pipes conduct the flow of water much as wires conduct the electric current. They offer some resistance to the flow: the longer and thinner the pipe, the less will be the current of water. Heat is, as a matter of fact, produced when water is made to flow through a pipe, just as heat is produced when electricity flows through a

wire, but the warming effect is not very great unless the water pipe is very fine and the water forced quickly through it.

The water flows through the pipes because there is a difference of level between the water in the cistern and the water in the tank at the bottom, in our example 10 feet. It is quite clear that, with a given circuit of pipes, the greater the difference of level the greater the current of water. If, for instance, the cistern were raised so as to make the difference of level twice as great as it is in the picture, the bent pipes being merely straightened out,

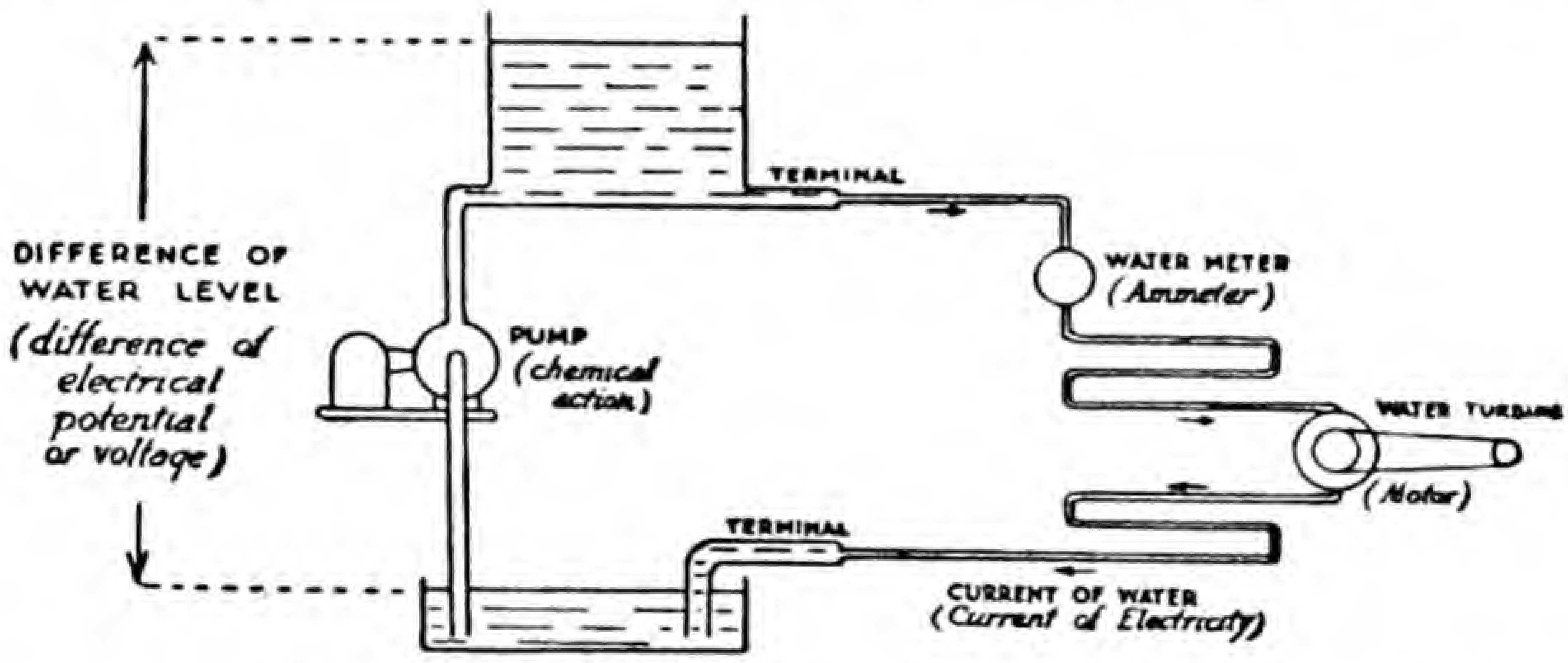


FIG. 40.—*The flow of electricity and the flow of water compared.*

and no extra piping brought in, twice as much water would flow through the circuit. The current flowing, then, depends on two things: first, on the difference of level, and secondly, on the resistance which the pipes offer to the flow; but while the current of water *depends* on the difference of level, it is, of course, not the same thing as the difference of level. We can measure, for instance, the difference of level in feet, but the current must be measured in gallons per second flowing past a given part of the pipe.

In electricity, in the same way, the current depends on

two things; firstly, on the resistance of the wires in the whole circuit, and secondly, on what we may call the difference of electrical level, or of *electrical potential*, as it is called in science. The little pump which keeps up the difference of water level corresponds to the chemical action in an electric battery, which keeps up the difference of electrical level. The pump only works when water is being run out of the cistern, just as chemical action only takes place when current is being taken out of the battery.

For instance, there is a difference of potential between the two poles of a single accumulator cell, and if we connect it with a resistance and an ammeter we can measure the current flowing. If now we connect two cells together, the positive of one to the negative of another, and join the two free terminals to the same resistance and ammeter, we shall get nearly double the current.[1] When we join the positive plate of the first cell to the negative of the second with a short wire, we bring the two plates to the same electrical level. The electrical level of the positive pole P of the second cell will then clearly be twice as much above the negative *n* of the first cell as the positive pole *p* of the first cell is above *n*. Cells joined up in this way, the positive of one to the negative of the next, are said to be joined "in series."

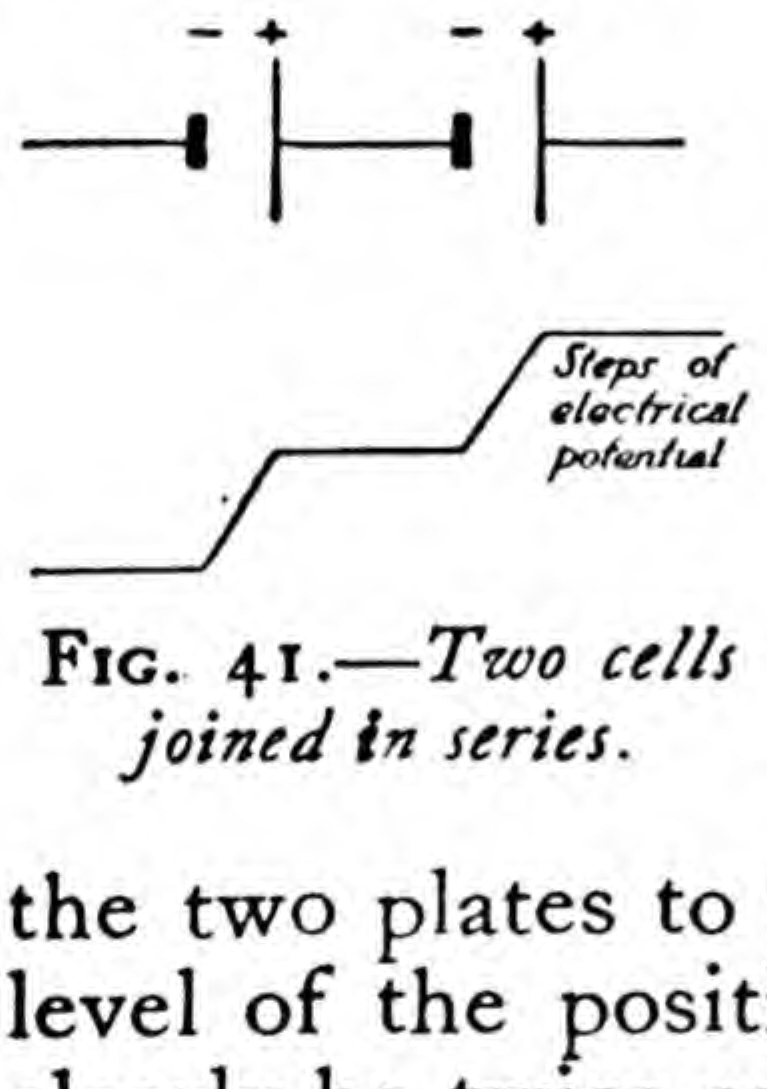


FIG. 41.—*Two cells joined in series.*

It is the difference of electrical potential that may be thought of as making current flow through the wires.

1 Not exactly double, because the cells themselves offer a little resistance to the flow of the current. But we need not trouble about these details at the moment.

The potential is therefore sometimes called the electro-motive force, which means electricity-moving force, and is shortened to E.M.F. or e.m.f.

We had better say at once that the electrical level or electrical potential is measured in volts, which will explain why the potential is generally called, by electrical engineers, simply the voltage. We can therefore take, for the present, electrical level, or electrical potential, or electro-motive force, or e.m.f., or voltage as meaning much the same thing. The current is measured in amperes; the electrical resistance in ohms. Volts are named after Volta, amperes after Ampère, ohms after Ohm, these being the names of three great men of science who were concerned in making clear the laws of current electricity.

People who know little of electricity often talk of, say, "an enormous current of 10,000 volts." This is just as absurd as saying "You have used a mile of water for watering your garden" or "Niagara Falls are ten million gallons high." Current must be measured in amperes. You can remember the right units from the sentence: "A potential difference of one volt sends a current of one ampere through one ohm," for that is how the units of potential, current and resistance are related.

It is very important not only for scientific purposes but also for everyday life to understand a little more about these volts and amperes. Suppose we have, firstly, a single small accumulator cell, secondly, a single very large accumulator cell, and, thirdly, the battery from a pocket battery. We say that the voltage of both accumulators is 2 volts, while that of the tiny torch is 4 volts. This sounds absurd at first, but let us consider the case of water. The level of a lake, which is fed by streams from the mountains, is, let us suppose, 20 feet above

that of a power station. The level of a cistern, kept up by the little pump, is likewise, let us suppose, 20 feet above a tank. Thirdly, let us imagine that the level in a glass bowl, supplying water to a toy fountain, is 40 feet above the jet: it is, say, on a roof and is kept full by the little boy who brings water in a small jug. Now we know that the greater the difference of water level, the more power can be obtained, yet clearly this little bowl would not drive a big water turbine, but the lake will. What is the secret of this contradiction?

The point is that if we joined the cistern to the great pipes bringing water to the water turbine, the level would sink at once, for all the water would run out of the cistern, and the little pump would be powerless to put it back fast enough, and with the bowl the 40 feet difference of level would fall to nothing even faster. The little boy with his jug can keep up the level as long as only a small current of water is taken from the bowl, but he could not keep up a level of an inch if the bowl were connected to the great pipes. The lake, however, which is supplied by many streams, can furnish all the current of water required by the water turbines, and still keep up its level.

Consider, now, the two accumulators. The small one can only supply a small current without losing its voltage, the large one can supply a much larger current and still stay at two volts. The torch battery can only supply an even smaller current than the small accumulators; if we connect it to a very small resistance we can get a big current, but only for a second or so. The high voltage cells in a wireless set that does not work off the mains can be very small because we only require a very small current for them, but there are many of them because we need a high potential.

In the end, even if we do not use them too much, the accumulators and the dry cells give out because the chemicals which act as the pump to keep up the difference of level of electricity, that is the difference of potential, between the two terminals of the cell, get used up. We know that with the accumulator we can restore the situation by passing a current backward through it, but the dry cells are finished for good.

The Supply of Electrical Power

In Book I we talked about what is meant in science by work, and saw that when a force moves a body it is said to do work. The amount of work is found by multiplying the force by the distance through which it moves the body; thus if a weight of 1 hundredweight is raised vertically through 100 feet, then 11,200 foot-pounds of work is done. If it falls through 100 feet it can do 11,200 foot-pounds. If the fall is very slow, because, for instance, it is lifting a heavy weight by a cord over a pulley, then, apart from the small work done against the friction of the pulley, it will do 11,200 pounds in lifting; if it is allowed to fall freely it will do no work, but get up a great speed, and we get the work performed when we stop it. Thus the water that runs down a wide steep pipe to work a water turbine comes out of the turbine very slowly, but if there was nothing to turn inside the turbine case it would come out very fast. It has sacrificed its energy to turn the turbine and do work. The work which a ton of water can do is found by multiplying 1 ton by the *vertical* distance through which the water has moved.[1]

[1] If we want the answer in foot-pounds we must write the ton as 2,240 pounds, and measure the distance in feet.

What the engineer wants is not just work, but work in a given time. He is not content that a pit engine shall pull up 20 tons through 625 yards,[1] taking perhaps all day over it: he demands that the engine shall do this work in a certain time. What he is interested in, then, is rate of doing work, or, putting it another way, in the work done per minute. The rate at which an engine does work is called its power; if it can do 33,000 foot-pounds in a minute, it is said to be a 1 horse-power engine. Another unit of power is expressed in the metric system. It is the kilowatt, and 1 kilowatt $=1{\cdot}34$ horse-power; for most purposes it is near enough to say 1 kilowatt $=\frac{4}{3}$ horse-power. A kilowatt really means 1,000 watts, and the watt is named after the great engineer James Watt, who made the steam engine into a practical servant of mankind, and showed how to measure its power. A watt, you will see, is only $\frac{4}{3000}$ horse-power, and so too small a unit to be used for engines, though you sometimes hear of the power of wireless sets being given in watts.

The work which can be done by the water running through the wide pipes from the lake to the water turbine is given by multiplying the weight of water by the height of the level of the lake above the turbine. The work done per minute, or power, will be given by the weight of water which runs through the pipe *per minute* multiplied by the height. The weight of water which runs by per minute is called the current of water. Thus, if the height is 300 feet, and there is a current of 10 tons of water per minute through the pipe, the power is

$$\frac{22{,}400 \times 300}{33{,}000} \text{ horse-power,}$$

[1] See example on p. 59 of Book I.

or about 203 horse-power. We multiply the difference of level which drives the water by the current of water to get the *power*.

The same rule holds in electricity. To get the work we multiply the difference of potential, or voltage, by the current;[1] if the current is measured in amperes, as it always is in practical cases, the answer is in watts. Thus, if the supply is at 220 volts, and we have an electric motor through which 5 amperes pass, the power of the motor will be about $\frac{5 \times 220}{1,000}$ kilowatts or $\frac{5 \times 220}{1,000} \times \frac{4}{3}$ horse-power, or just under $1\frac{1}{2}$ horse-power.

When you hire a car you say how long you want it for: that is, you buy so many horse-power for so long. That is the way electricity is bought, so many kilowatts for so many hours. One kilowatt for an hour is called one Board of Trade Unit, or B.T. Unit, or just a Unit, if it is clearly understood that we are talking of electrical power. This is very useful to know, as it will tell you quickly how much things cost to run by electricity. Let us take an example. Suppose that a B.T. Unit costs 3d. in your district: how much will it cost to run an electric lamp for an hour? On the lamp you will find marked the power which it requires to run it—60 watts is an ordinary sort of figure, so we will suppose that yours is a 60-watt lamp; 1 kilowatt, which is 1,000 watts, costs 3d. for one hour, and so your lamp will run for an hour at a cost of $\frac{60}{1,000} = \frac{3}{50}$ of 3 pence, or $\frac{9}{50}$ of a penny, which is a little less than a farthing. Or, suppose you have a

[1] We are speaking of direct current. Alternating current is rather too difficult for us at this stage.

radiator on a 200-volt direct current circuit, and the radiator takes 4 amperes of current to heat it. This is $\frac{4 \times 200}{1,000}$ kilowatts, so that to run your radiator for an hour will cost $0 \cdot 8 \times 3 = 2 \cdot 4$ pence.

To avoid any possibility of confusing all these units we will make a little table. Other units, whose names we need not trouble with, are sometimes used by men of science; the ones given are those that you will meet in ordinary life.

Electrical Thing Measured.	*Unit.*
Difference of potential, also called e.m.f.	Volt
Current	Ampere
Resistance	Ohm
Power	Kilowatt or horse-power
Quantity of electrical energy, or work.	Kilowatt-hour, also called Board of Trade Unit.

The ordinary town house contains some simple examples of the general effects of electricity which we have mentioned. The electric bell, for instance, shown in Fig. 42 makes use of the magnetic effect of a current in the following way. M is an electro-magnet. One end of the wire with which it is wound goes to the terminal T_1, while the other end is fastened to a flat spring S which carries a piece of soft iron, or armature, as it is called, to which the striker is attached. The other terminal of the bell goes to a screw which is arranged just to touch a stud carried by the armature, as shown at C. The terminals T_1, T_2 are connected to the wires which run to the bell push, and a battery is included in the circuit. Now suppose the push pressed down. The current will run

from T_2 to T_1 through the screw and the armature round the winding of the magnet. As soon as this happens the electro-magnet pulls in the armature, and the striker strikes the bell. But, when the armature moves in, the stud leaves the screw at C, and the current can no longer pass, so that the magnetic force stops and the spring moves the armature back again, until the stud touches the screw, and the process goes on all over again, as long as the

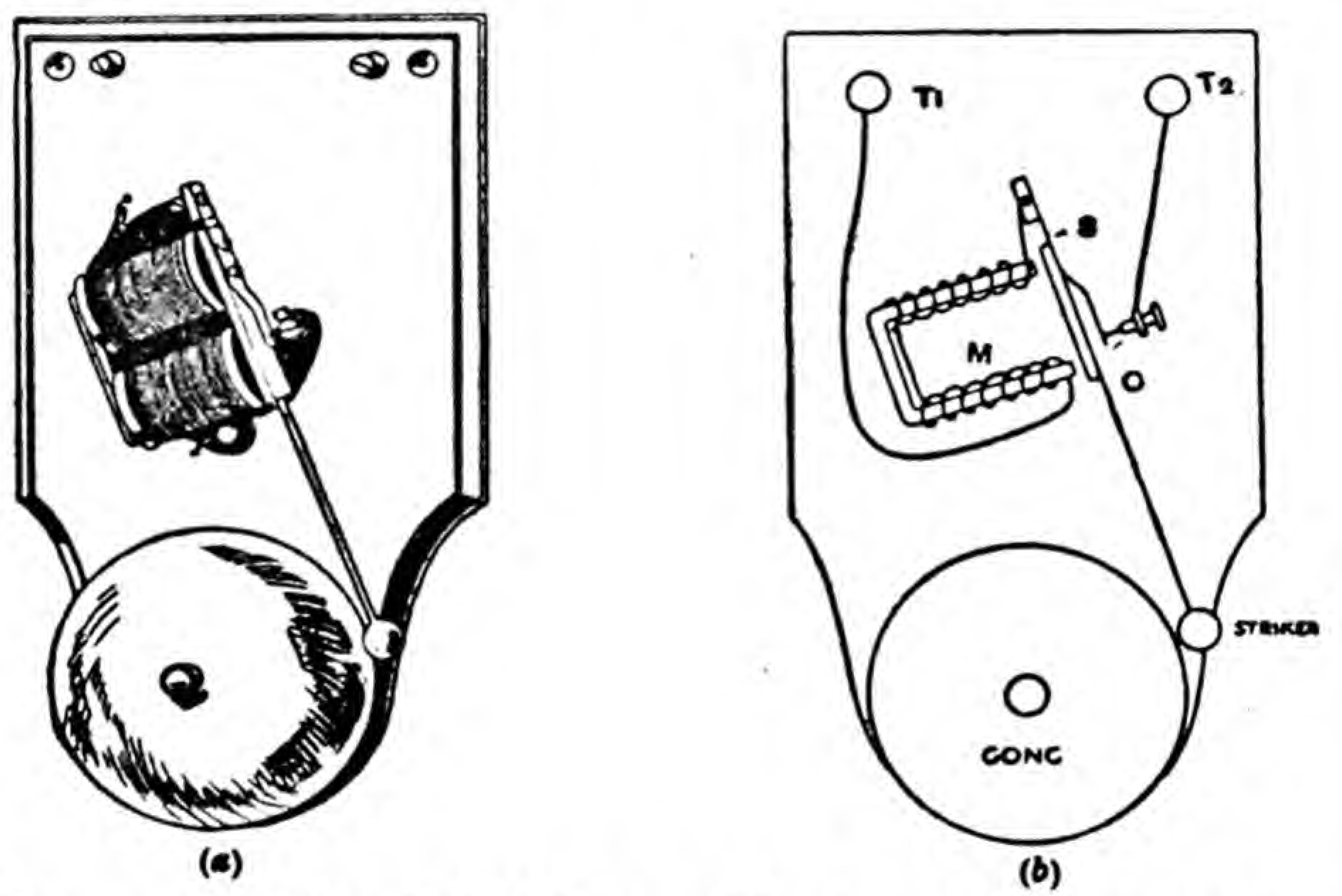


FIG. 42.—*Electric bell* (*a*) *outside view;* (*b*) *working parts.*

push is kept down. The electric bell, then, is an example of electro-magnetism.

In the house there will also be a fuse box, which is a protection against accident to the house wiring. In the ordinary way, when the switch is turned on, the current has to flow through a large resistance, a lamp or radiator, and so is prevented from being too large. Suppose, however, that by accident the insulation of the wires leading to the lamp gets worn through, so that the wires themselves

touch, or that a piece of metal gets by accident across the lamp terminals, or that in some other way an accidental join of very low resistance, which electricians call a "short circuit," occurs between the wires of the circuit If this happens, since there is practically no resistance in

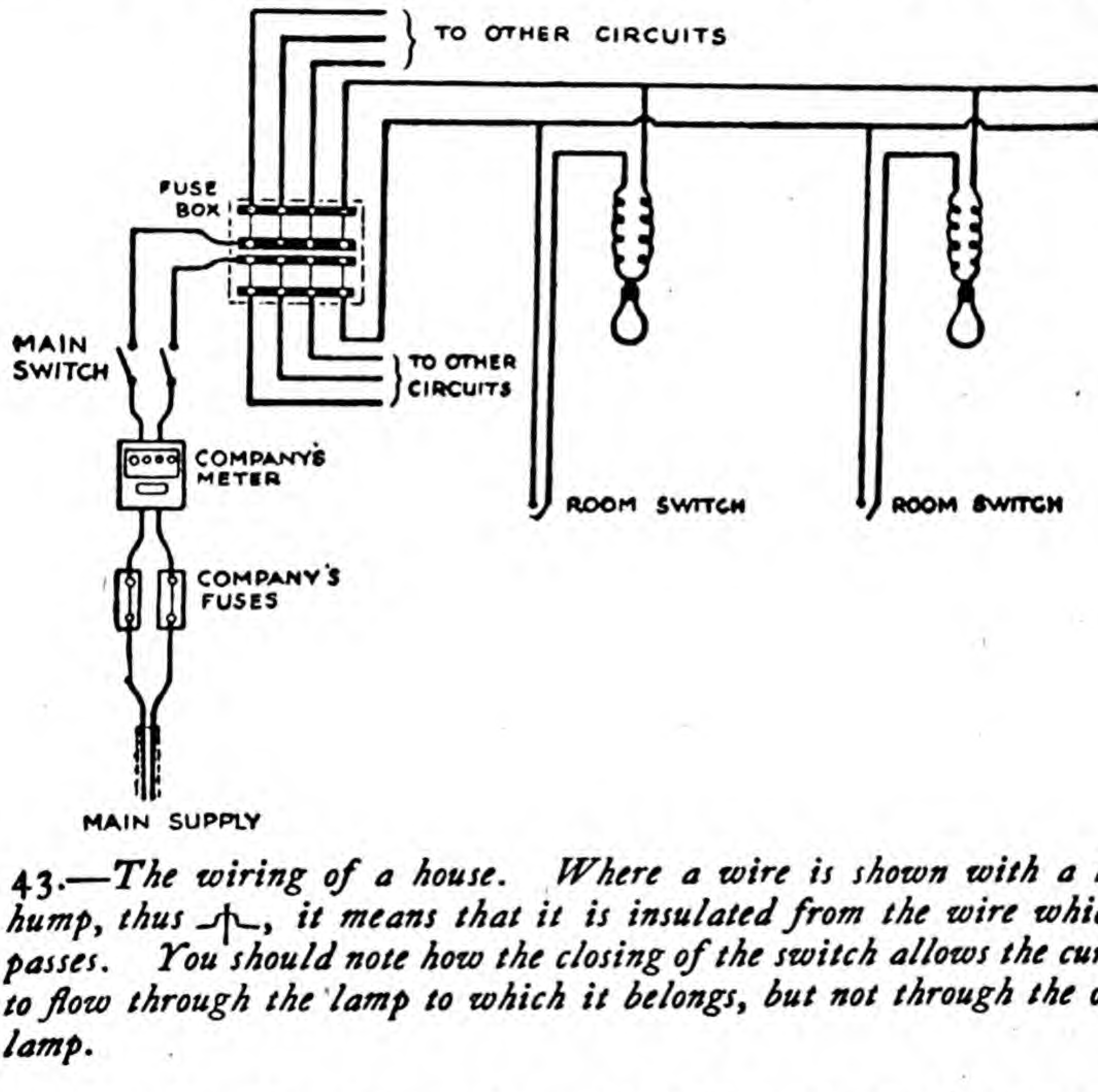


FIG. 43.—*The wiring of a house. Where a wire is shown with a little hump, thus* ⌐∩⌐, *it means that it is insulated from the wire which it passes. You should note how the closing of the switch allows the current to flow through the lamp to which it belongs, but not through the other lamp.*

the whole circuit, when the switch is put on the current will be very large, so large that dangerous heating will take place, and part of the circuit wire may melt. If this melting or excessive heating were to take place at certain parts of the circuit it might set the house on fire, but in any case it would be difficult to find out where and how

much the wire was damaged, and so would be a serious matter for the householder.

Now a fuse is a piece of wire which, owing to its thinness, if it is of copper, or its low melting-point, if it is of tin, melts with a current smaller than the greatest current which the wires of the circuit can safely carry, but larger than that which they are ordinarily required to supply. Thus an ordinary lighting circuit may be carrying 3 amperes when all the lamps are on, and the wires of the circuit may be safe with currents up to 6 amperes: in such a circuit a fuse which melts with 5 amperes, generally called for short a 5-ampere fuse, may be used. If a short circuit takes place, or if for any reason more than 5 amperes flows in the circuit, the fuse melts, the current stops, and the lights go out, thus protecting the circuit and giving warning that there is something wrong. The fuse is a weak place deliberately made in the circuit, which gives way before the rest of the circuit can become overheated. It may be called an electrical safety-valve. It also makes certain that the failure shall take place where it can be easily found and repaired.

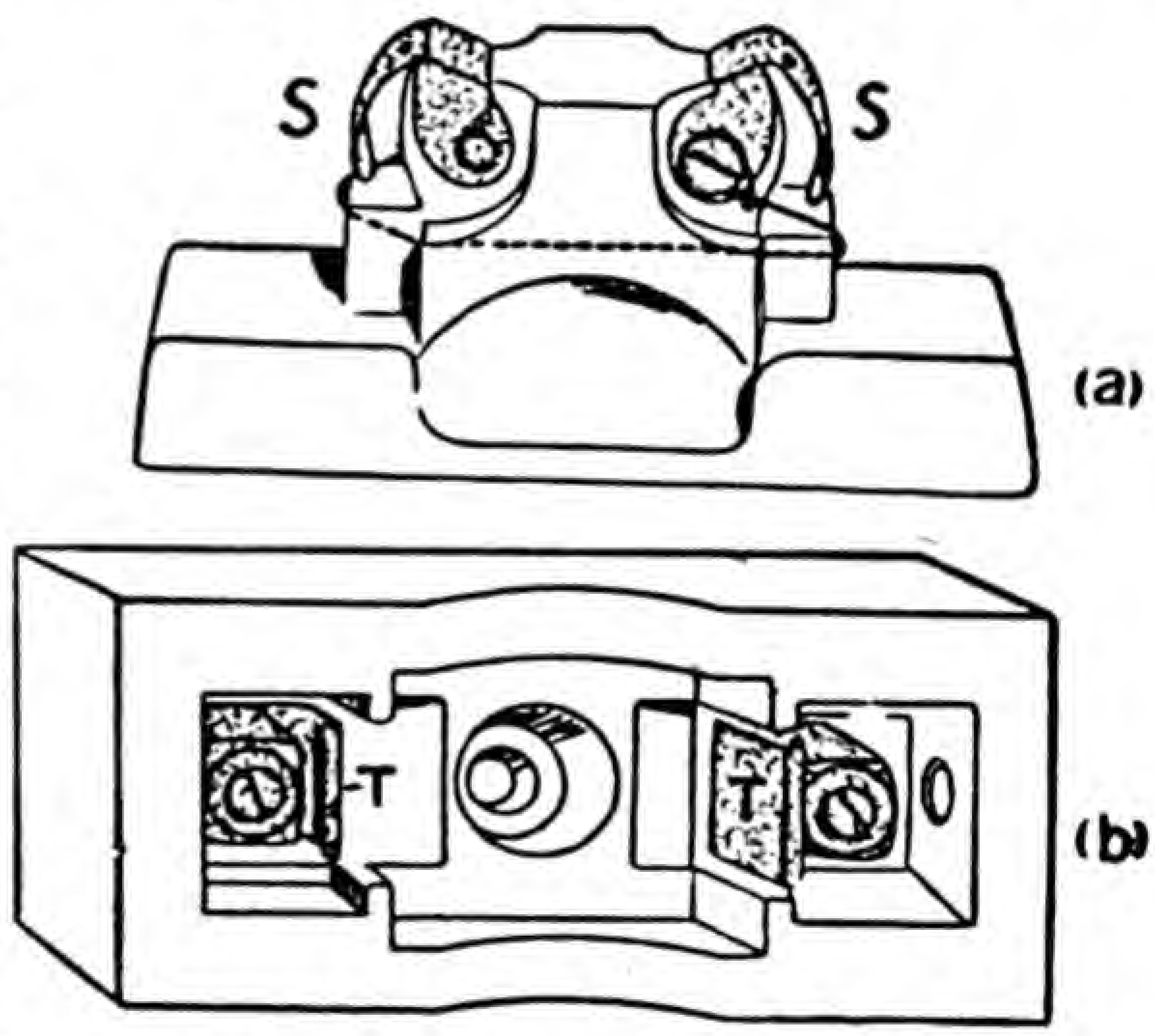


FIG. 44.—*A fuse. The fuse wire, shown dotted in the upper picture, is joined to the metal springs S S. When the part (a) is pushed into the holder (b), the springs S S fit between the metal pieces T T, which are joined up to the wires of the circuit.*

Fuse wires are often mounted in porcelain holders, the two ends being attached to copper pieces which push

into spring holders, as shown in Fig. 44. If the wire fuses it stains the porcelain, so that a rapid glance will tell which of several fuses has "blown," as it is called. The holder can be quickly pulled out, the stain wiped off, a new wire put in, and the holder replaced.

Frictional Electricity and Current Electricity are the same Electricity

We said earlier that all electricity is of the same nature, and yet the frictional electricity machine seems to produce very different effects from the electricity in the house circuit. Even a small electrical machine gives good sparks with the knobs an inch or two apart; if two wires from the house circuit are put even a quarter of an inch apart no spark passes. (Great care must be taken not to let them touch, or a short circuit occurs as explained in the last section, and the fuses will be blown.) Yet if we connect an electric motor or a radiator or a lamp to the frictional machine we get no effect. Why is this?

The reason is that with the frictional machine we get a very large difference of potential, but a very small current, while with the ordinary house circuit or with accumulator cells, we have a lower potential, but a much larger current. The electricity of a frictional machine giving a spark corresponds to a pint of water falling through several hundred feet, the flow of electricity through the house circuit to a large current of water, say several gallons a minute, moving through pipes under a difference of level of a few feet. A small machine can easily produce a difference of potential of twenty thousand volts, but the current which it furnishes will be something like a ten millionth of an ampere, while

the current through an ordinary electric lamp on a 200-volt circuit is about a third of an ampere. The electricity falls through a much greater difference of electrical level in the case of the frictional machine, but, even taking this into account, the electrical power of the machine is exceedingly small, not nearly enough to light an ordinary lamp. It is the lack of quantity, not a difference in quality, that distinguishes the electricity of the frictional machine.

It can, however, be shown that the passage of electricity from the friction machine can produce the effects which we know to be produced by the ordinary electric current — that is, the heating effect, the magnetic effect, and the chemical effect. The heating effect can be shown by the apparatus illustrated in Fig. 45. Through the bulb runs a fine platinum wire, attached to two terminals outside the glass. To the bulb is attached a tube containing a coloured liquid, shown black in the picture, so that if the air is heated and expands, the liquid is forced back, and the movement can be measured on the scale. If now a series of sparks are passed, by connecting one terminal to one side of the machine, the liquid will move, showing the heating of the wire which is produced by the passage of the electricity which is carried by the spark.

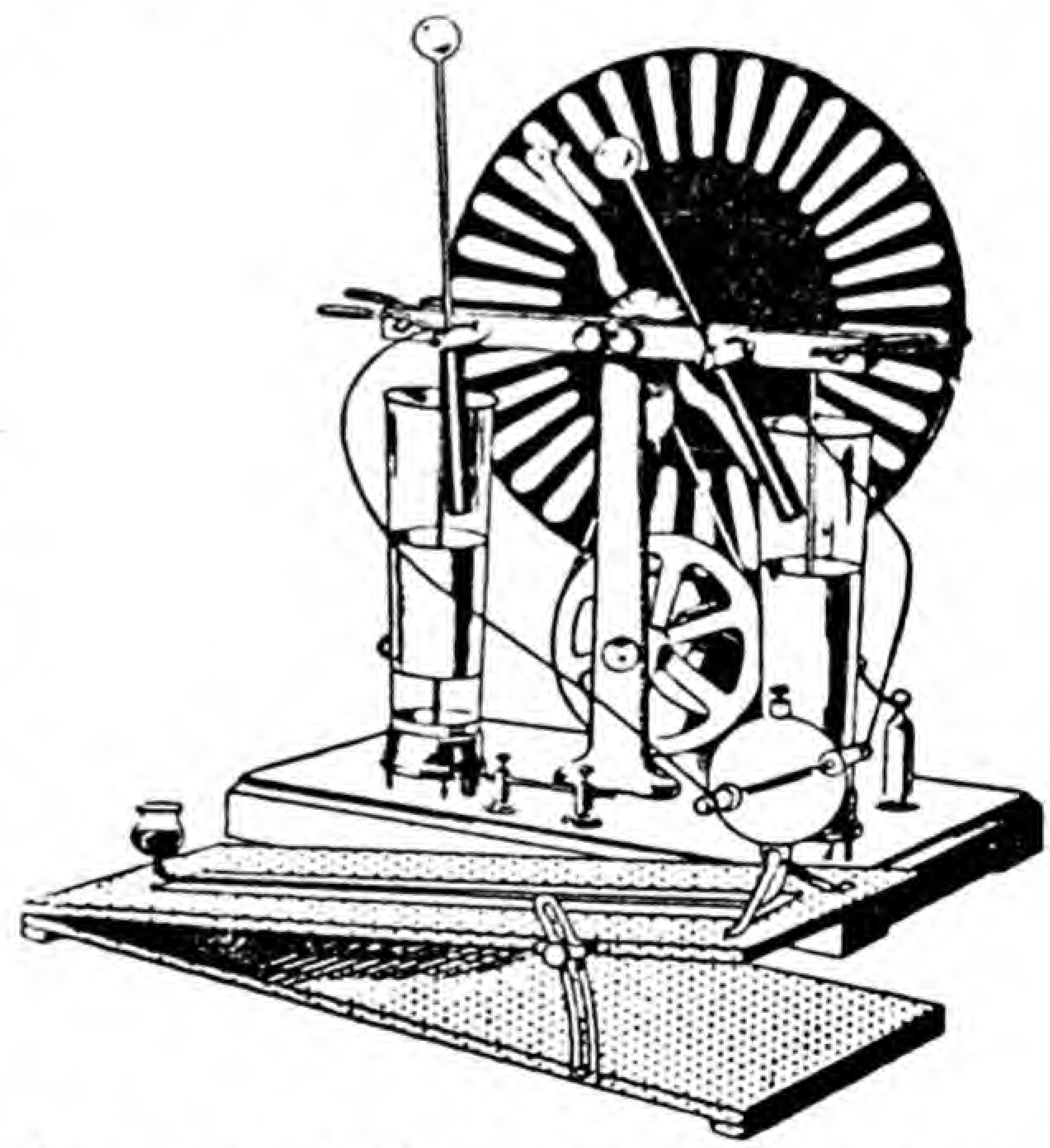


FIG. 45.—*The heating effect of the electricity from a frictional machine.*

The magnetic effect can be shown by passing a spark so that coil of wire in which we put a steel knitting-needle, on to a the electricity carried by the spark goes through the wire. We first prove that the needle is not magnetic, by showing that it will not attract iron filings. After the passage of the spark the needle will be found to be a magnet. Once more, the electricity of the spark, passing through the wire, produces the same effect as an ordinary current from a cell.

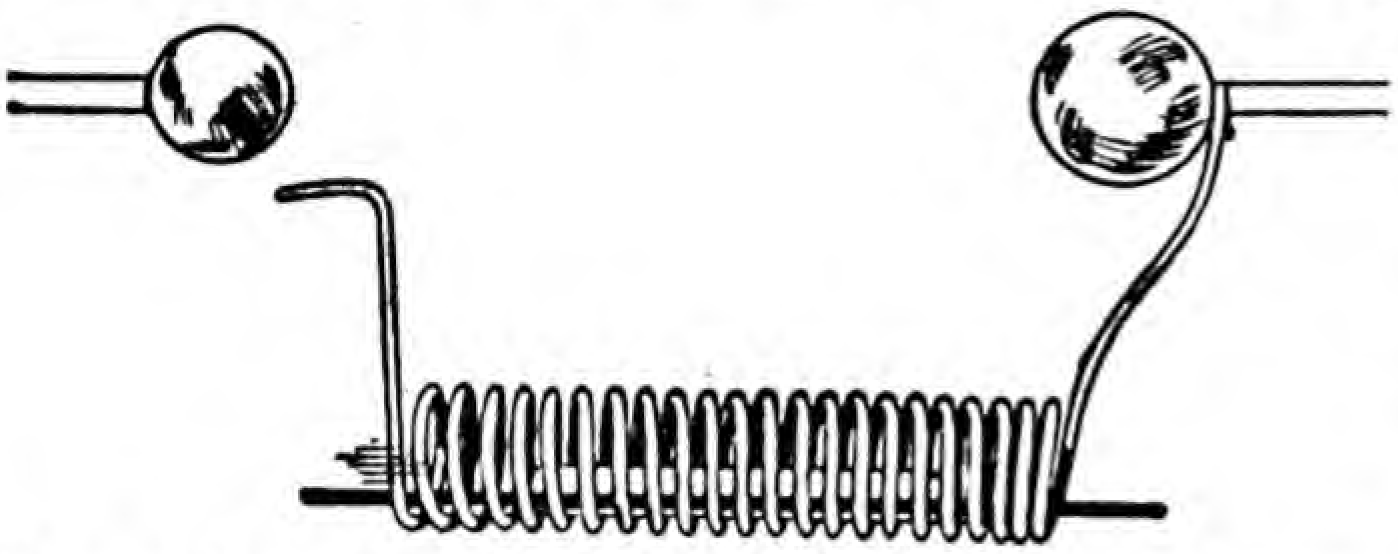


FIG. 46.—*The magnetic effect of electricity from a frictional machine. The knitting-needle in the coil, which lies in a glass tube, is magnetic after sparks have been passed.*

The chemical effect can be simply shown by wetting a piece of paper with a paste of ordinary starch, to which a little of the chemical known as potassium iodide has been added. If we press the wires from an accumulator hard on to the paper, about half an inch apart, so that the current passes through the starch, in a short time the wire from the positive pole will produce a blue tinge, which gives a useful way of telling the positive from the negative pole, if they are not marked. The blue is due to a chemical change which the current produces: it sets free from the potassium iodide the iodine, which turns starch blue.[1] If, instead of using an accumulator, we press the two balls of the electric machine, or wires from them, on to the paper, and turn the handle for some time, the same effect is produced. This is a sign that the electricity from the two different sources has the same chemical action. Water can also be broken up by the

[1] See Book II, p. 181.

frictional electricity, but very slowly with an ordinary machine.

It is even possible to get a flash of light from an electric lamp simply by the frictional electricity of a well-rubbed rod of dry ebonite, but it must be a neon lamp and not a wire filament lamp. In such a lamp the current passes through the gas neon contained in the bulb, and causes a reddish glow, as we have mentioned before. It requires very little electrical energy to make such a neon lamp light up, which is one reason why this kind of light is so widely used for advertising signs.

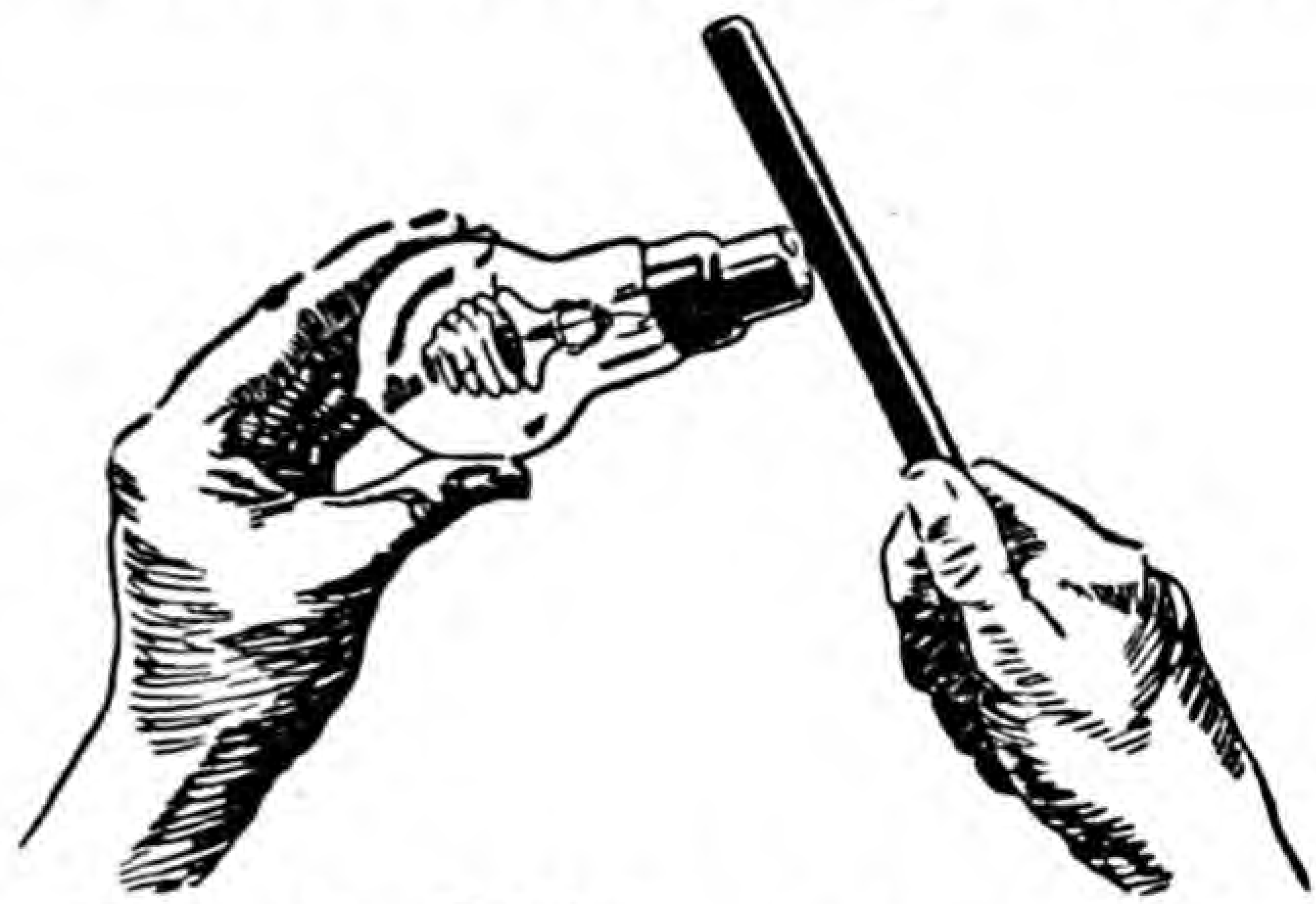


FIG. 47.—*Lighting a neon lamp by frictional electricity.*

When we rub a rod of ebonite it gains the property of being able to attract scraps of paper, and we say that it has an electric charge. When we do the little experiment just described, of lighting the neon lamp by touching it with the rubbed rod, we shall find that it has lost its charge. The charge, then, must have run away through the lamp, and, in doing so, produced just the same effect as an ordinary electric current. This suggests that the ordinary current is just a movement of charge through the wire, and this is what we now know to be the fact. One experiment which proves this clearly was performed with an insulating disc, on which were stuck pieces of thin metal foil. The foil was given an electric charge, and the disc was then spun very fast, so that the charge of electricity on the metal foil moved rapidly. Small mag-

netic effects were produced, of just the kind that we should expect from a small current. The experiment is not at all simple to do, on account of the high speeds necessary, but it has been successfully accomplished. It cannot be carried out in an ordinary school laboratory.

An electric current, then, is the same thing as a movement of electric charge, but exactly how the charge passes through the metal is a matter about which some of the greatest men of science are still puzzling their brains. So you must not mind if it is not quite clear to you how it happens.

CHAPTER III

MAGNETISM

North Pole and South Pole—Magnetic Attractions—The Magnetism of the Earth—Electro-magnetic Induction

North Pole and South Pole

THE word magnet is derived from Magnesia, a town in Asia Minor, near which in olden days were found pieces of a stony mineral which had the property of attracting iron. These were the earliest known magnets. The magnetic stone is an oxide of iron (that is, a chemical compound of iron and the gas oxygen) which is nowadays called magnetite, but formerly it was called lodestone (also spelt loadstone), which means, in old English, way-stone, because from it could be made a compass which showed the way to sailors. Before the Christian era the Greeks and Romans knew of its power of attracting iron, but, although at one time it was said that the Chinese knew even earlier of its power of showing the north, there is no certainty that a compass was ever used before the twelfth century.[1]

Fig. 48.—*An old lodestone, with ornamental mounting.*

[1] People often make the mistake of thinking that the twelfth century means the years from 1200 to 1300. If we remember, however, that the first century must be the years from 1 to 100, and not from 101

Let us consider the way in which the early compasses were made, as this will teach us some of the properties of magnets. The ancients used a piece of loadstone, but to-day it is easier to take a bar magnet, which behaves just as a strong loadstone does. The magnet is placed in a V-shaped groove cut in a large, flat cork, and the cork floated on water. It will be found that it turns until one end of it points towards the north: if this end be marked with chalk, and the magnet turned round into some other position and let go, the same end will always come back and point towards the north. One particular end of a magnet, then, always seeks the north, and may be called the north-seeking end of the magnet, or, as it is generally called for short, the north pole of the magnet. The other end is called the south pole. We may call our magnet a floating compass, and such floating compasses were the first kind used by sailors. To-day the compass magnet does not float, but is supported by a pivot on which it can turn freely, both in the little compasses that scouts and soldiers carry, and in the compasses of ships.[1] It is interesting to note that in the early days the mysterious

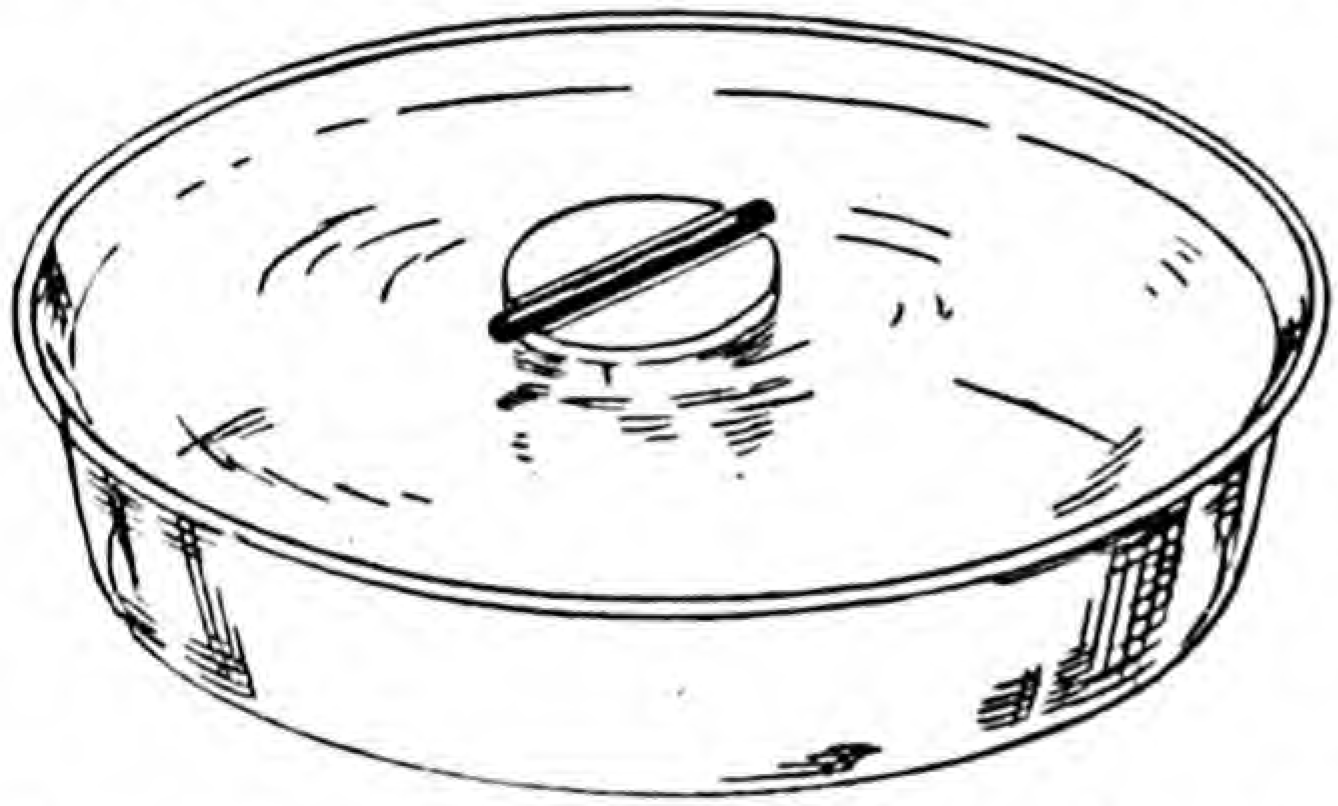


FIG. 49.—*A floating magnet. It points north and south, but stays in the middle of the basin.*

---

to 200, we see that the twelfth century must be the years from 1101 to 1200, just as the eleventh year of a boy's life is from the time he is 10 years old until he is just 11.

[1] The earliest pivoted compass was described in 1269.

behaviour of the compass magnet was often set down to magic: in fact, a thirteenth-century Italian writer said of it: "No master mariner dares to use it, lest he should fall under the supposition of being a magician; nor would even the sailors venture themselves out to sea under his command if he took an instrument which carries with it so great an appearance of being constructed under the influence of some infernal spirit." We may smile at this, but we are not so free from all error nowadays that we can afford to smile very long. Some people will not go anywhere without a mascot.

The floating magnet shows the pointing to the north, and so does the pivoted magnet, but the floating magnet shows something more. It will remain in the middle of the vessel, and is not pulled, as a whole, either to the north or the south. This tells us that the south pole is pulled as strongly to the south as the north pole is to the north. Two such pulls may clearly produce a turning, but cannot produce a movement of the point round which the magnet turns. If, for example, there is a plank lying on a table, with a rope fastened to each end, and two equally strong boys pick up each a rope, and pull, the plank will come into line so as to point an end at each boy, but it will not travel from the table. The behaviour of the floating magnet shows us that in every magnet the north pole and the south pole must be equally strong.

This seems strange, for it would at first thought seem possible to break the magnet in the middle, so that we should have a north pole without a south pole and a south pole without a north pole. If this really did happen, and we floated the north pole bit, it would move away to the north side of the bowl, and only stop when it reached the edge, just as the plank would move if only one boy

were pulling. What actually happens when we break a magnet, however, is that new poles form at the new ends; a new south pole in the piece containing the old north pole, and a new north pole in the place containing the old south pole. However often we break the magnet the same kind of thing happens, as shown in Fig. 50. This can best be proved by magnetising a knitting-needle, in the way described on p. 87, and gripping one end in a vice, when a blow will easily break it. Each piece, when floated on cork, will behave as a complete magnet. Or, if we do not break the magnet, but hammer the north pole, which weakens it, the south pole weakens at the same time, so that once more if we float the magnet it will not move to one side, but only turn so as to point north and south. Whatever magnet we have, and whatever we do to it, it will always have a north and south pole of equal strength.

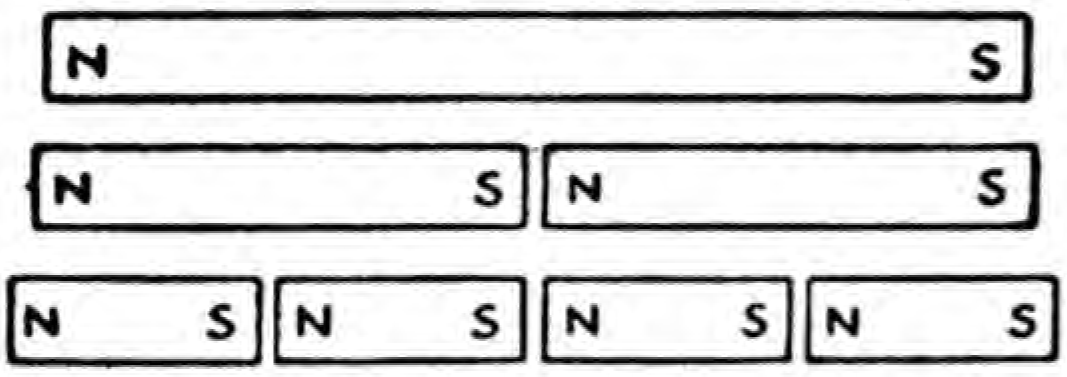


FIG. 50.—*When a magnet is broken new poles form, so that every bit has its north and its south pole.*

MAGNETIC ATTRACTIONS

In Book I we spoke of a simple experiment which showed that if we pivoted a magnet, and marked one end of it, then one end of a second magnet would attract, but the other would repel, the marked end of the first magnet. We can now take things a little further. Suppose we have two long, thin, pivoted magnets,[1] which are commonly called magnetic needles, although not really needle-shaped. We place them sufficiently far apart for them

[1] Such as are illustrated in Fig. 42 of Book I.

not to act noticeably on one another, let them come to rest, and mark the north poles with a spot of ink, or with a tiny piece of gummed paper, or in some other way. Very likely it will be found to be marked already in some way. If we now take one off its pivot and bring its north pole to the north pole of the other magnet, we shall find that they push each other away, and if we bring the south poles near together, we shall find that they likewise push one another away. The north pole of one magnet attracts, however, the south pole of the other. Two poles which are both south are called like poles, and so are two poles which are both north, but south and north are unlike poles. It is therefore said that:—like magnetic poles repel one another, but unlike magnetic poles attract one another.

This reminds us at once of the behaviour of electric charges: two positive charges repel one another, and so do two negative charges, but negative and positive charges attract. In the electric case, then, like charges repel but unlike charges attract. We have the great difference that in the electrical case we can get a positive or a negative charge alone on a body, say an insulated ball, while, as we have seen, we cannot get a north magnetic pole on a piece of steel without an equal south pole. All we can do, if we want to find the action of a north pole, is to use a longish magnet and hold it so that the south pole is as far as possible from the test pole. We can never get completely rid of the action of the south pole, but we can, however, make it very small compared to that of the other pole.

The action of magnetic poles on one another can be shown very plainly by the very strong cobalt-steel magnets, made in the shape of round rods, which can be

bought for a few shillings. The north poles can easily be found by hanging up the magnet in a little loop of paper attached to a fine thread, or, easier still, by testing the ends of the magnet on a compass needle. If two such magnets are placed side by side on a smooth table, with north pole to north pole, and south to south, they will rapidly roll away from one another, owing to the repulsion at both ends. If they are turned so that north lies next to south they will roll together and cling very closely. It is also amusing to make one of the magnets float in the air. Two pieces of glass must be fixed parallel, as shown in Fig. 52, to prevent the floating magnet from twisting sideways so as to escape as far as possible from the repelling poles. If, then, a horseshoe magnet be arranged in the position shown, a cobalt-steel magnet placed between the glass guides can be made to float, by arranging for its north pole to come over the north pole, and its south pole to come over the south pole, of the fixed

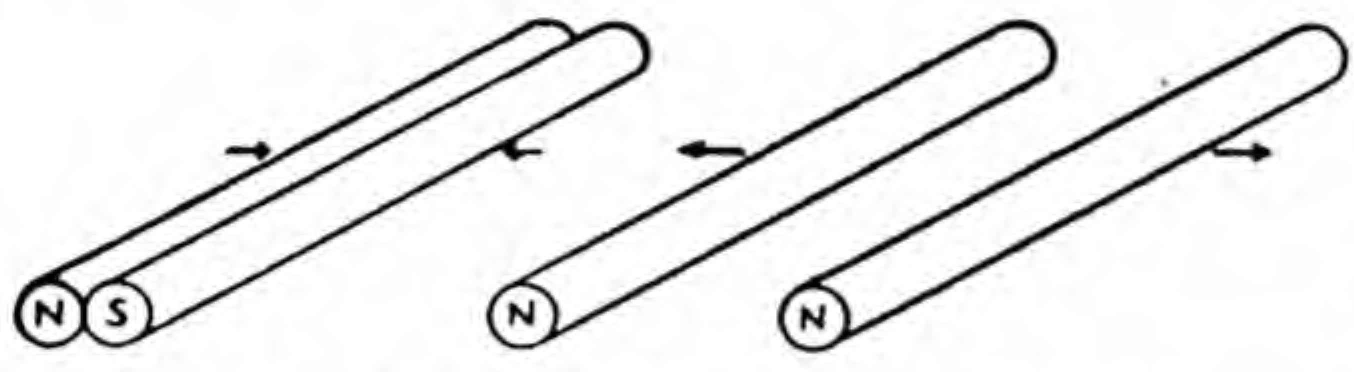


FIG. 51.—*Repulsion and attraction of cylindrical magnets. When they are placed with unlike poles opposite they attract; when one is reversed, so that like poles are opposite, they repel one another.*

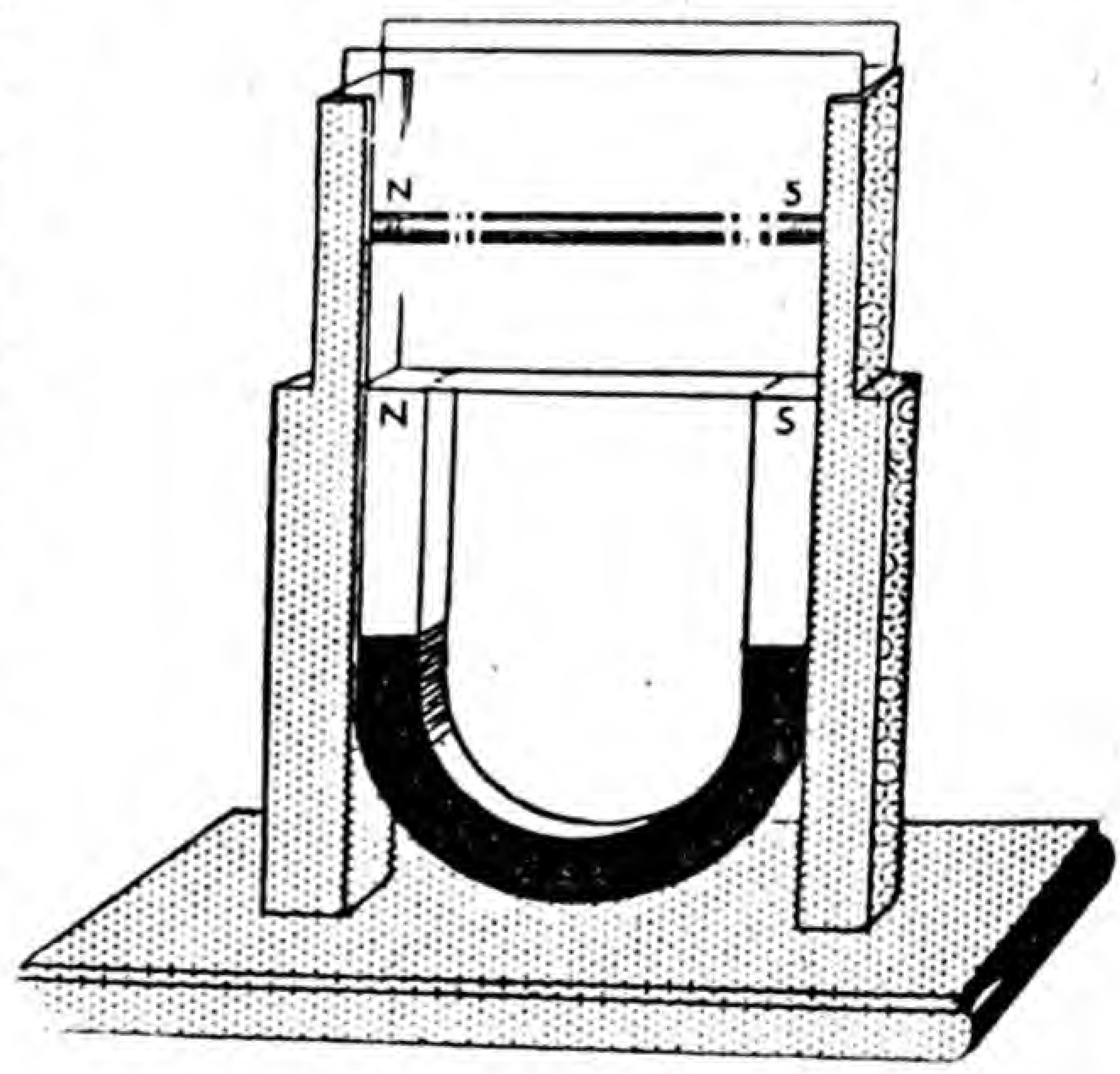
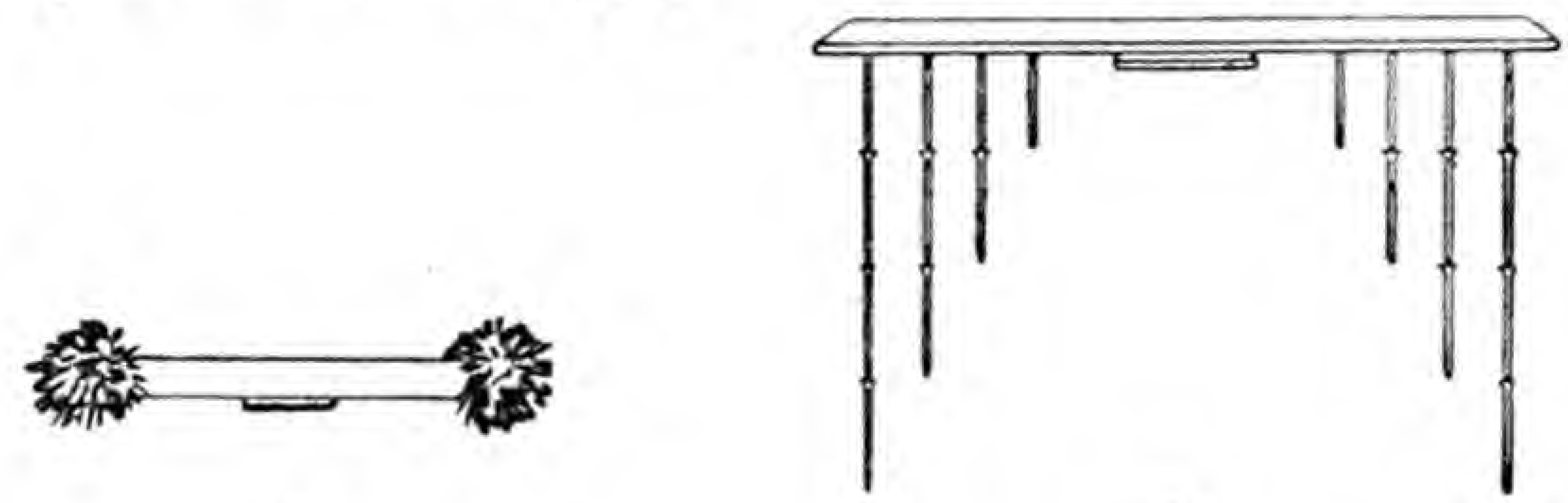


FIG. 52.—*A magnet floating in air, between glass plates.*

magnet. The horse-shoe magnet can, of course, be hidden if desired, or a cobalt-steel bar magnet can be used in its stead.

A magnet behaves as if the attractive power were gathered together near the ends of the magnets, which is why we speak of poles. The middle part of the magnet does not exert a magnetic force. It is easy to show this by the help of iron filings, which are very useful in mag-



(a) (b)

FIG. 53.—*The magnetic force is strongest near the ends of a magnet, as shown by: (a), iron filings, and (b), nails.*

netic experiments. If the magnet be dipped into a heap of iron filings, it will be found that they gather at the ends, but that practically none cling at the middle, as shown in Fig. 53*a*. Or we may make the test with steel nails, the so-called French nails. At the end the magnet will carry, say, four nails, near the middle only one nail, and just in the middle no nail at all, as shown in Fig. 53*b*. Some magnets are made with balls at the ends, and then the poles are practically at the centres of the balls.

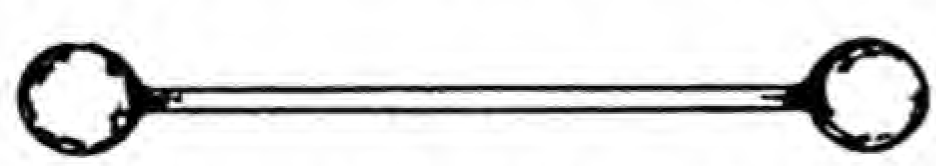


FIG. 54.—*A ball-ended magnet.*

All round a magnet there is a magnetic force, which will act on pieces of iron or steel. The further we go from the magnet, the weaker the force becomes. Any place

where there is a magnetic force is called a magnetic field, so that the man of science says that the magnet is surrounded by a field of magnetic force. In the same way an electric charge is surrounded by a field of electric force. The iron filings can be made to show us, not only that the force is there, but also the direction in which it is acting at any point. For this purpose a sheet of thin, stiff card, as smooth as possible, is placed over a bar magnet, and sprinkled with iron filings. If the card is then gently tapped the filings arrange themselves into lines which show the direction of the magnetic force, and are called *lines of force*. The filings should not be spread too thickly.[1] Instructive pictures may be made of the lines of force round one magnet, as shown in Fig. 55*a*; and of the lines of force round two magnets, arranged, as shown in Fig. 55*b*, either north pole to north pole, or south pole to south pole. In the attraction case the lines of force run from each pole to the unlike pole of the opposite magnet; in the repulsion case they bend aside to avoid one another.

Any piece of iron or steel which is placed in the field of force of a magnet itself becomes a magnet. Let a rod of soft iron be fastened upright in a wooden stand, as shown in Fig. 30, with one end close above some iron filings, which it does not attract. If a good bar magnet, such as one of the cobalt-steel magnets already spoken of, be brought up so that one of its poles is close to the upper end of the rod, the lower end will at once attract

[1] If it is wished to keep the picture of the lines of force given by the filings, they may be stuck in place by spraying the card with a solution of shellac in methylated spirits, which is what artists do when they wish to preserve a charcoal drawing. The spirit evaporates and the shellac is left, fastening the filings.

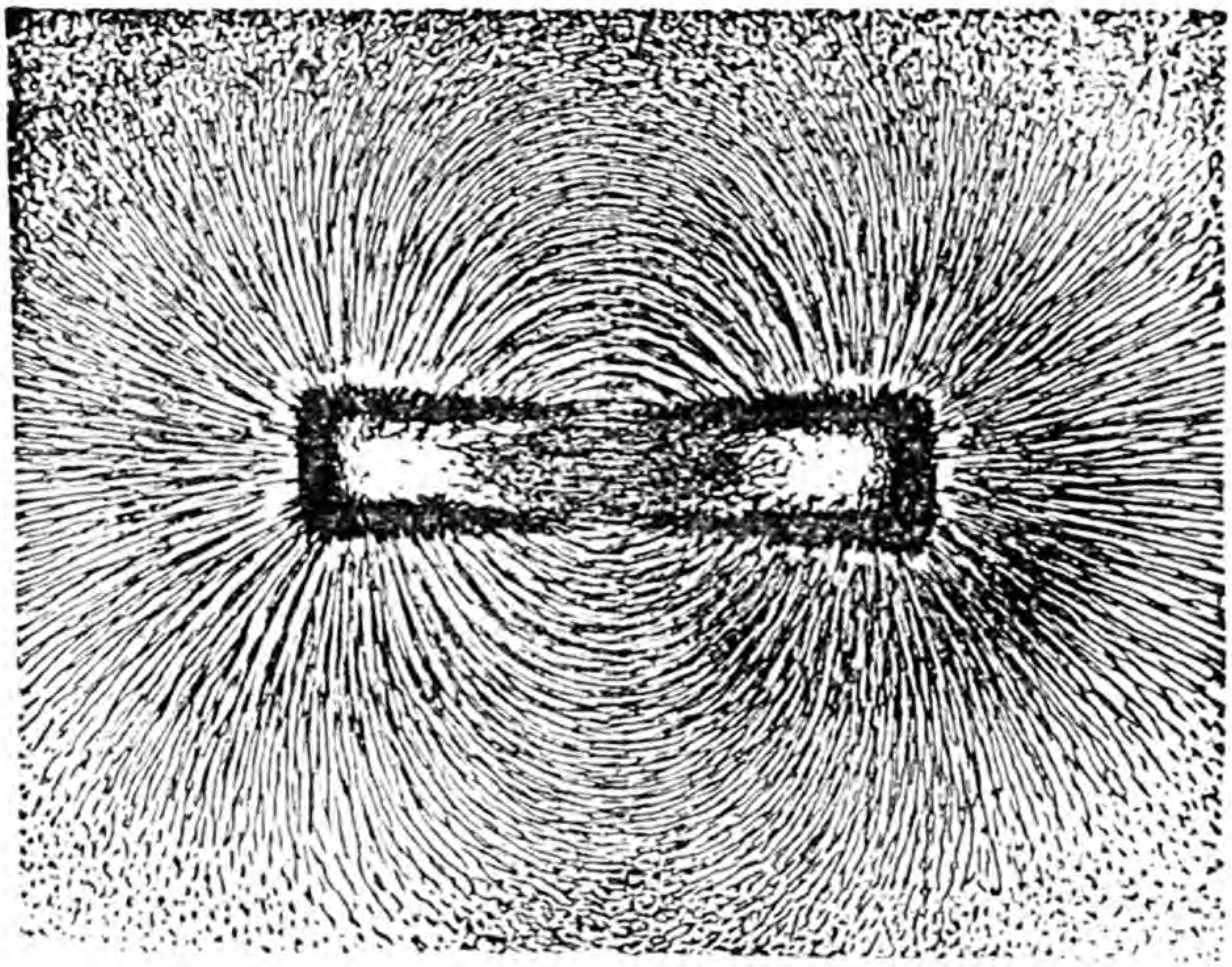


FIG. 55*a*.—*Lines of magnetic force round a single magnet.*

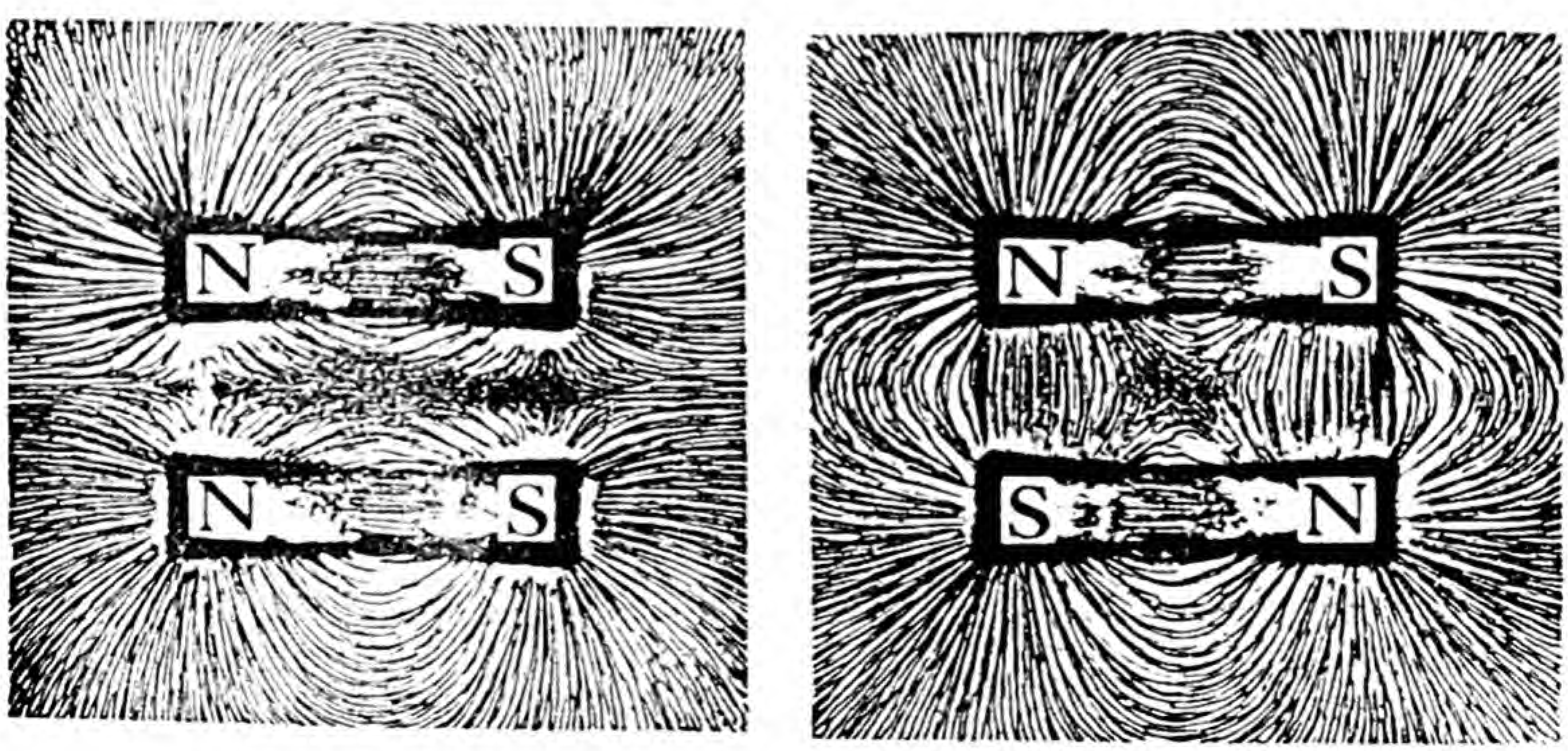


FIG. 55*b*.—*Lines of magnetic force round two magnets.*

the filings; if the end of the bar magnet is made to touch the end of the iron rod the action on the filings will be particularly strong. When the magnet is taken away all, or nearly all, the filings fall off the iron. If, however, a hard steel rod is used instead of the iron rod, once more the filings stick when the magnet is brought up, but many

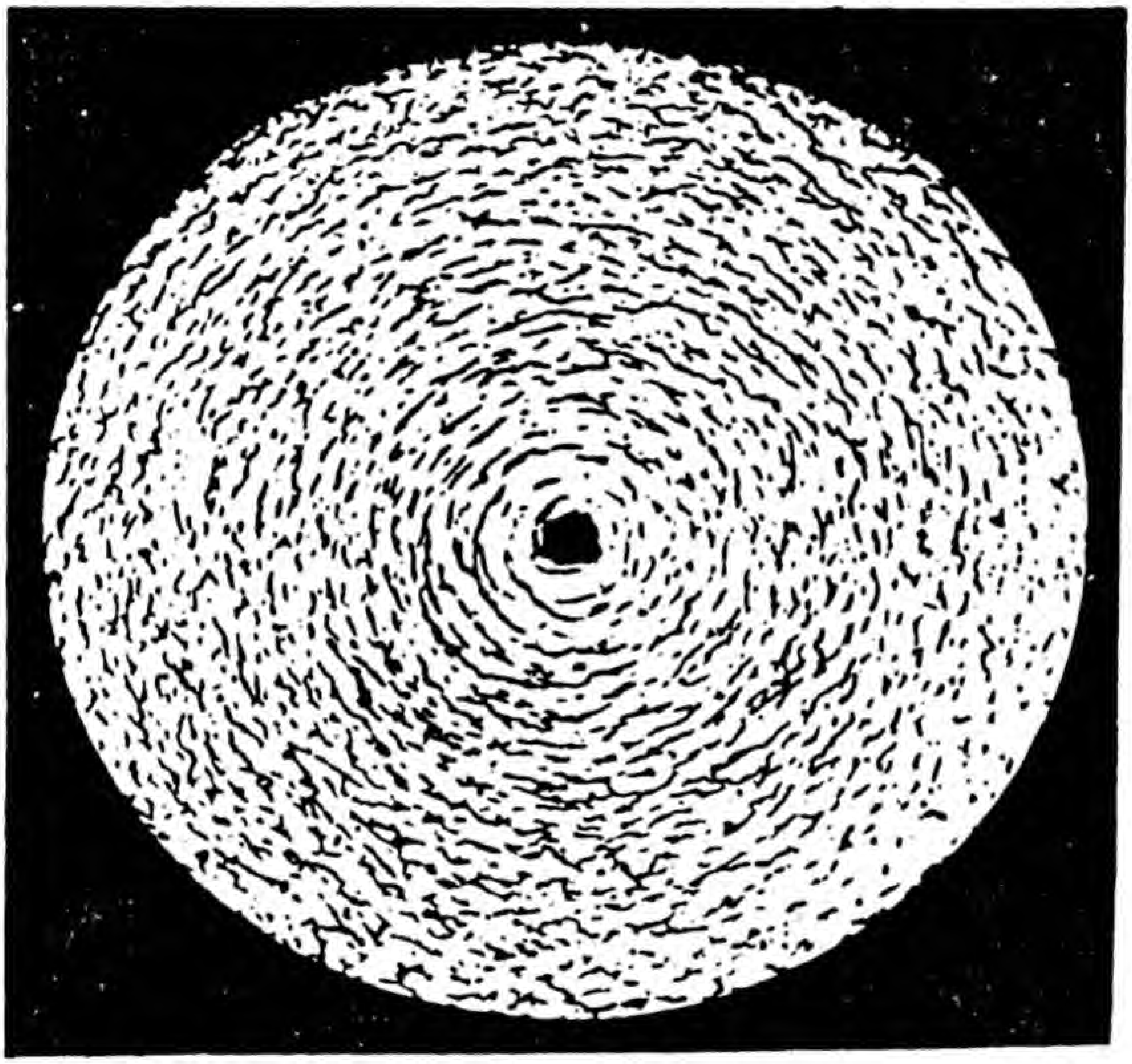


FIG. 56.—*Circular lines of magnetic force round a current, shown by iron filings.*

remain when the magnet is taken away. The steel rod has itself become a permanent magnet.

The magnetism which appears when a steel or iron rod is placed in a magnetic field is called induced magnetism. If it disappears when the field is taken away it is called temporary magnetism; if it remains it is called permanent magnetism. An ordinary bar magnet is often called a

permanent magnet, because it is always a magnet, unlike the piece of iron in an electro-magnet, which is only a magnet while the current is flowing round it. It is the magnetic field round the current that induces the magnetism, in just the same way as the magnetic field of a bar magnet does. The magnetic field round a current can be shown by iron filings, by placing a stout copper wire upright through a sheet of card strewn with filings, and letting a heavy current pass through the copper wire. On tapping the card circular lines of force appear.

The magnet made of a steel rod by simply bringing a magnet up to it is a very weak one. A better one can be made by stroking the steel rod, always in one direction, with one pole of a magnet, as shown in Fig. 57*a*.

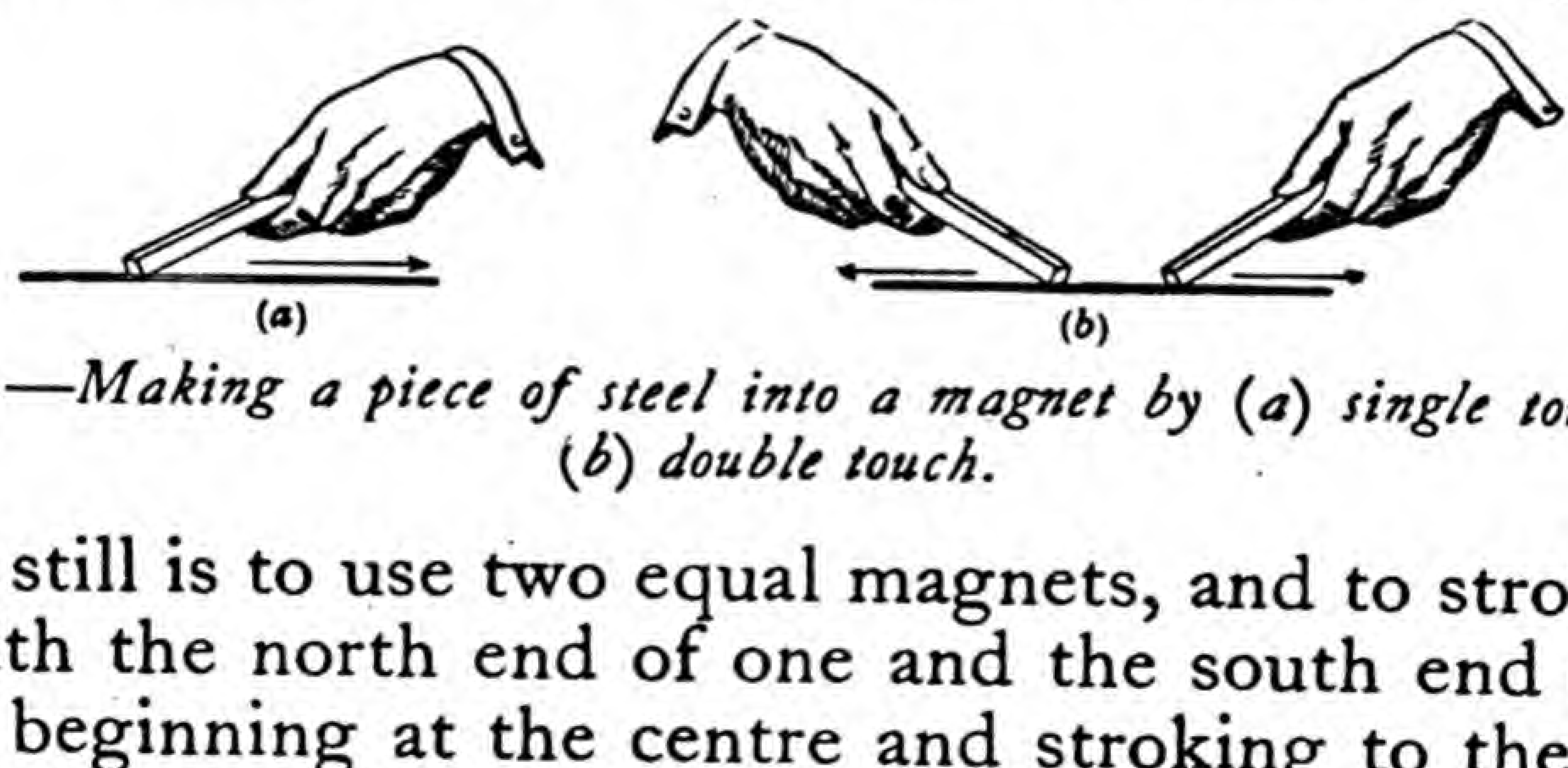


FIG. 57.—*Making a piece of steel into a magnet by (a) single touch and (b) double touch.*

Better still is to use two equal magnets, and to stroke the rod with the north end of one and the south end of the other, beginning at the centre and stroking to the ends, and then repeating, as shown in Fig. 57*b*. This is called the method of double touch. In this way quite good magnets can be made of knitting-needles and pieces of clock spring. Still another way of making a magnet is to hammer a steel bar, not in the earth's weak magnetic field, but in the magnetic field near the poles of a strong electro-magnet. Of course, if a steel rod is placed in a coil of wire through which a strong electric current is passed it becomes a permanent magnet.

The only substance which people generally think of as magnetic is iron, but rods of nickel and cobalt will also become magnets if placed in a strong magnetic field, although they have no permanent magnetism. All substances are actually magnetic to a very slight extent, but their magnetism is far too weak to be noticed except by very difficult and delicate experiments. The pull of a magnet on a piece of copper would only be about a millionth of that on a piece of iron in the same place.

The magnetic force passes undisturbed through all substances except those which become magnets by induction—that is, for all ordinary purposes, except iron, nickel, and cobalt. If, for instance, a pivoted compass needle be placed on the table, and a magnet arranged near it so as to turn the needle aside, it will be found that putting a sheet of glass, or of brass, or of any other substance (except those just named), between magnet and compass, will make no difference to the position of the needle. If, however, a thick sheet of soft iron is put round the compass, the needle will show no particular attraction to the magnet. Or a bar magnet may be placed on the table, with a sheet of glass resting on it; the lines of force can be nicely shown with iron filings on the glass. With a thick sheet of iron, used in the same way, only very feeble lines of force can be found. A sheet of iron shields off the magnetic force, or nearly all of it, if it is thick enough.

The Magnetism of the Earth

We have been careful to say that the magnet needle of the compass points "towards" the north, and not "to" the north, for it does not point straight at the North Pole, or

true geographic north—that is, at the imaginary line round which the earth is rotating. In what direction, then, does it point?

In England the needle points about 12 degrees west of true north—that is, of the meridian through the place where the compass is; at other parts of the earth's surface it points at other angles, at some places west of the true north, just as it does in England, at others east of the true north. The angle between true north and magnetic

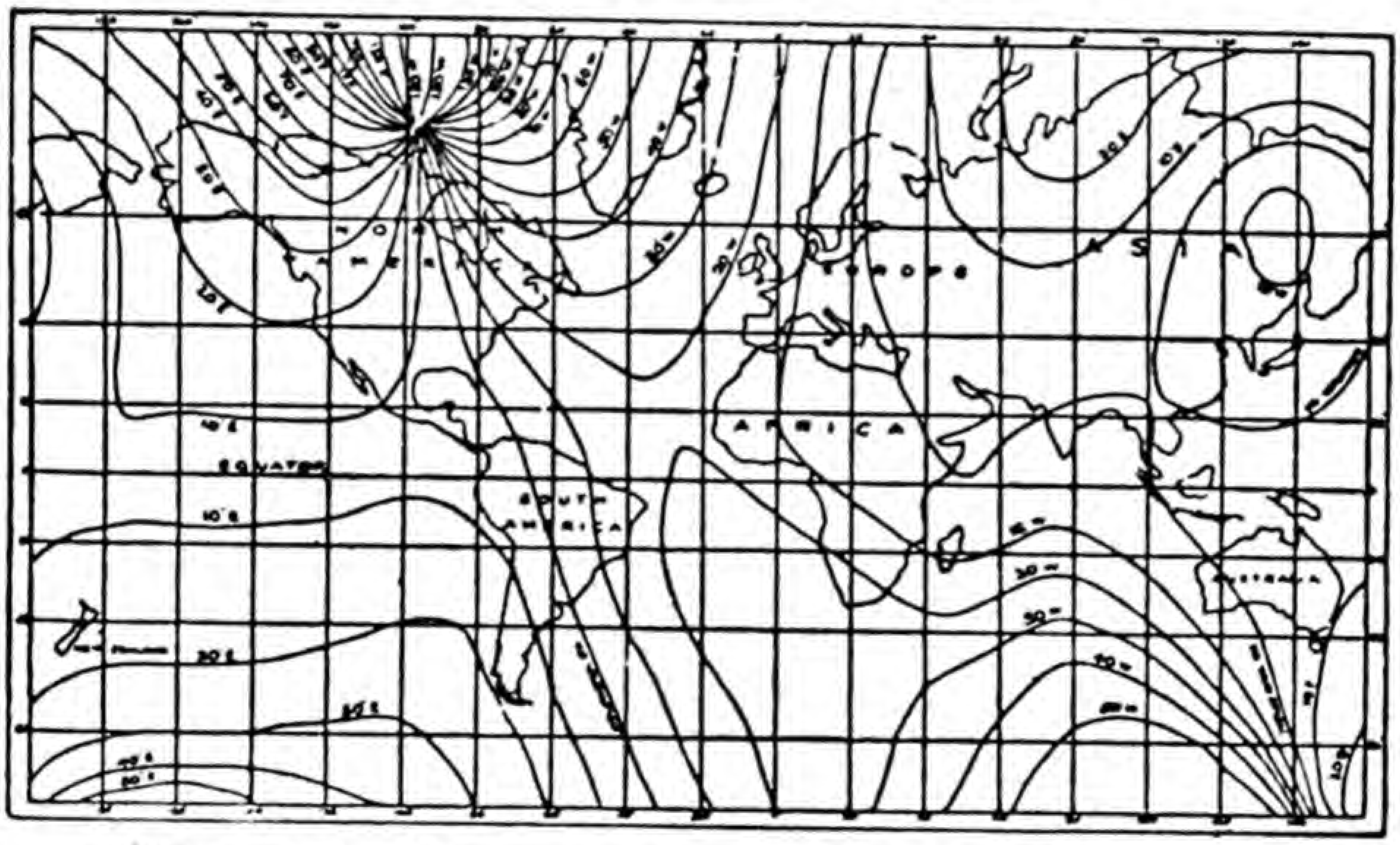


FIG. 58.—*Lines of equal magnetic declination.*

north (as the direction given by the compass is called) is named the *magnetic declination*. Thus we say that the declination in England is 12° W. Far north or far south the declination may be very large; thus, near Iceland it is 30° W., at the extreme south of Greenland 40° W., in southern Chile, in South America, 20° E. It is, of course, very important for sailors to know from their compasses where the true north is, so maps are made to show what the declination is at various places. On these maps lines are drawn, each one of which connects points at which the

declination has the same value; these lines of equal declination are called isogonal lines. Thus in Norway, Eastern France, the Gulf of Lyons, Timbuktu, and Madagascar the declination is about 10° W.; the positions of these places are joined on the map by a line marked 10° W. A map showing such lines is given in Fig. 58; on sailors' charts of similar parts of the earth's surface lines will be marked in between the ones drawn here, which are for every 10°. Thus, from the map given here it is difficult to say what will be the declination at Cape Town; it will clearly be more than 20° W. and less than 30° W., since Cape Town is between 20° W. and the 30° W. line. Actually it was about 25° at the year for which the map is drawn. The maps have to be frequently redrawn, for, strange to say, the declination is slowly changing all the time, at some places as much as 2° in ten years.

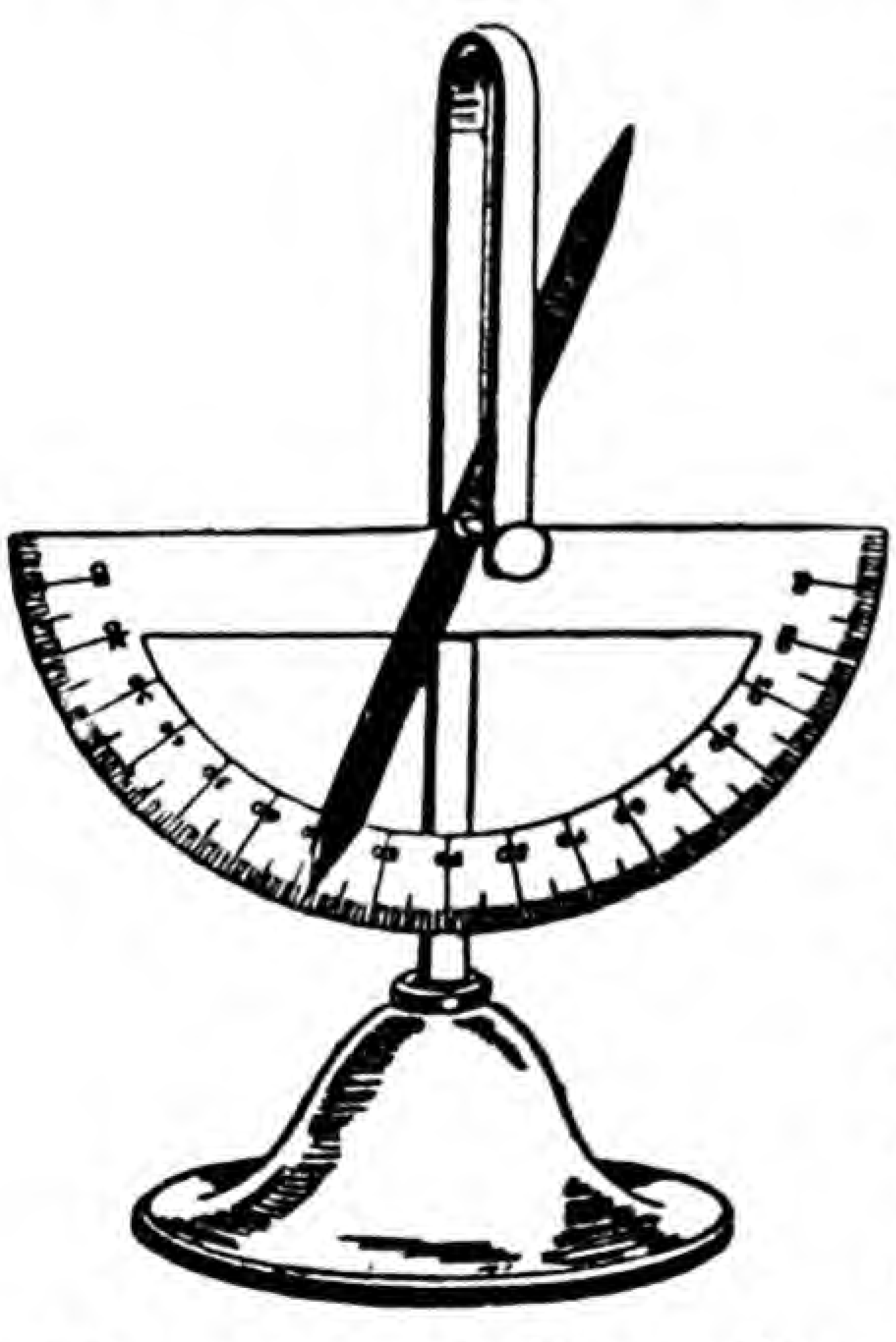


FIG. 59.—*A dip needle.*

If a needle made from a piece of flat steel, and pivoted in the ordinary way so that it balances nicely, be then magnetised by, say, the method of double touch, it will be found that it no longer balances well, but dips down at the north end in England, or at the south end in Australia or South Africa. This looks as if the magnetic force on the needle were not along the surface of the earth, but somewhat downwards. It will clearly be easier to observe this if we pivot the needle in a different way, so that it can turn round a horizontal axis, as shown in

Fig. 59. If the stand of such a carefully balanced needle is turned so that the needle is in the line through the magnetic north (for it cannot now turn to the north of itself, mounted as it is) it will be found not to balance horizontal, but to point strongly downwards, or dip, as it is called. In the picture the needle is shown as it will stand in New York; at London the dip is about 67°; further north the needle will dip more; further south

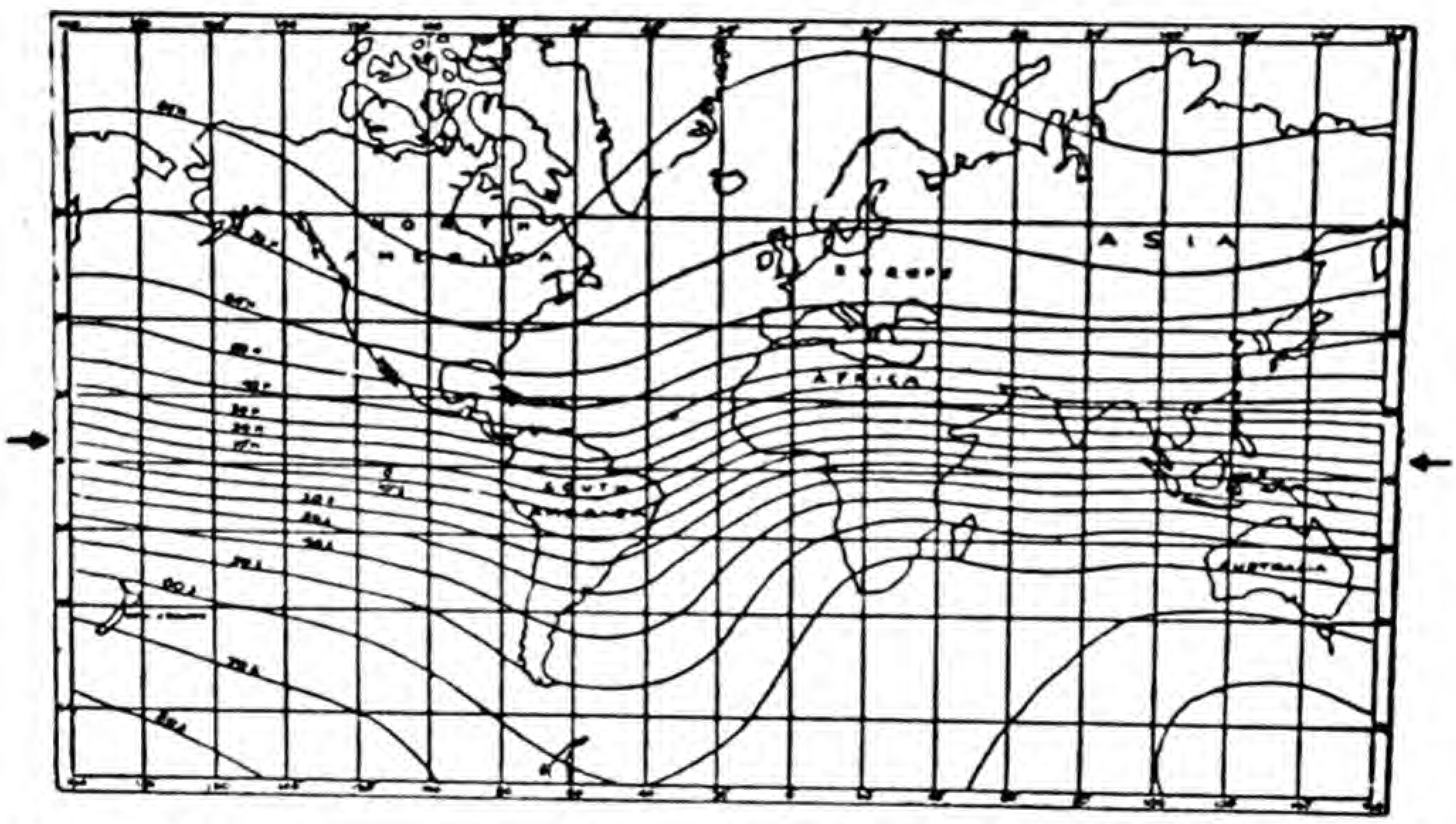


FIG. 60.—*Lines of equal magnetic dip. The line of no dip is indicated by arrows at the side.*

it will dip less, until in the neighbourhood of the equator it does not dip at all, but stands horizontal. South of a rather wavy line which runs round the earth near the equator (it is shown by arrows in Fig. 60) the needle dips at the other end; that is, the south pole of the needle dips, and the north is up in the air. The dip at various points on the earth is shown in Fig. 60, from which it is clear that in the north of Scotland, to take an example, the dip is 70°, since the line marked 70° passes there.

It will be seen that the compass needle behaves exactly as if there were a great magnet buried in the centre of the earth, about in the position shown in Fig. 61. The needle is horizontal in the neighbourhood of the equator because, although the north pole is pulled inwards, the south pole is equally strongly pulled inwards. Further north we are nearer the south pole of the earth magnet; further south nearer the north pole of the earth magnet. It may seem strange to see the south pole of the earth magnet lying towards the north, but it must be remembered that what we call a magnetic north pole is one that seeks the geographical north, and that unlike poles attract one another. It is not believed, of course, that there is an enormous bar magnet buried in the earth, but the compass behaves just as if there were. We may, at any rate, say that the earth itself behaves as a great magnet. This magnetism of the earth itself has a great effect on many things that happen in the atmosphere—for instance, it accounts for the way that the polar lights hug the poles, and do not appear equally all over the earth. How it does this is a very interesting question, but is too difficult to talk about here.

FIG. 61.—*The earth behaves as if a great magnet were buried in it. The arrows show the position of the dip needle at different points, the head of the arrow being the N pole of the needle.*

From Fig. 60 it will be seen that the dip gets greater and greater as we approach the North Pole, and reaches 80° when we are still some distance from the pole. This looks as if, somewhere near the North Pole itself, the magnet of the dip circle ought to point straight downwards: it ought to stand on its head. In fact, it does so, not exactly at the geographical North Pole, but at the spot shown on the map in Fig. 61, and the place where it behaves in this way is called the magnetic pole of the earth. It is the same spot where all the lines of declination run together, as shown in the map of Fig. 58. There is a north magnetic pole and a south magnetic pole. The north magnetic pole is on latitude 74° and longitude 96° W. of Greenwich, and was first found by Captain James Clark Ross in 1831, and again fixed by Captain Amundsen at the beginning of the present century. The south magnetic pole has not yet been reached, but it must be about 72° S. and 155° 16′ E. Captain Douglas Mawson, of Shackleton's expedition, actually found a place where the dip was 89·8°: only a fifth of a degree from quite vertical!

The ship's compass is so important that a special word about it seems necessary. Anyone who has ever had an opportunity of looking at one knows that there is no needle to be seen, as in the ordinary scout's compass or surveyor's compass, but instead a round card marked with the "points of the compass," as they are called. These are, first of all, north, south, east, west; then, midway between north and east comes north-east; midway between north and north-east comes north-north-east; midway between north-east and north-north-east comes north-east-by-north. The other divisions are similarly called; you can easily name them and then check

yourself by the initials on the card in Fig. 62. The north point is specially marked with the old heraldic lily, called "fleur de lys" (French for lily flower; Shakespeare calls it the flower-de-luce). Between the "points" the quarter points are marked, and usually degrees are also marked round the edge, as shown.

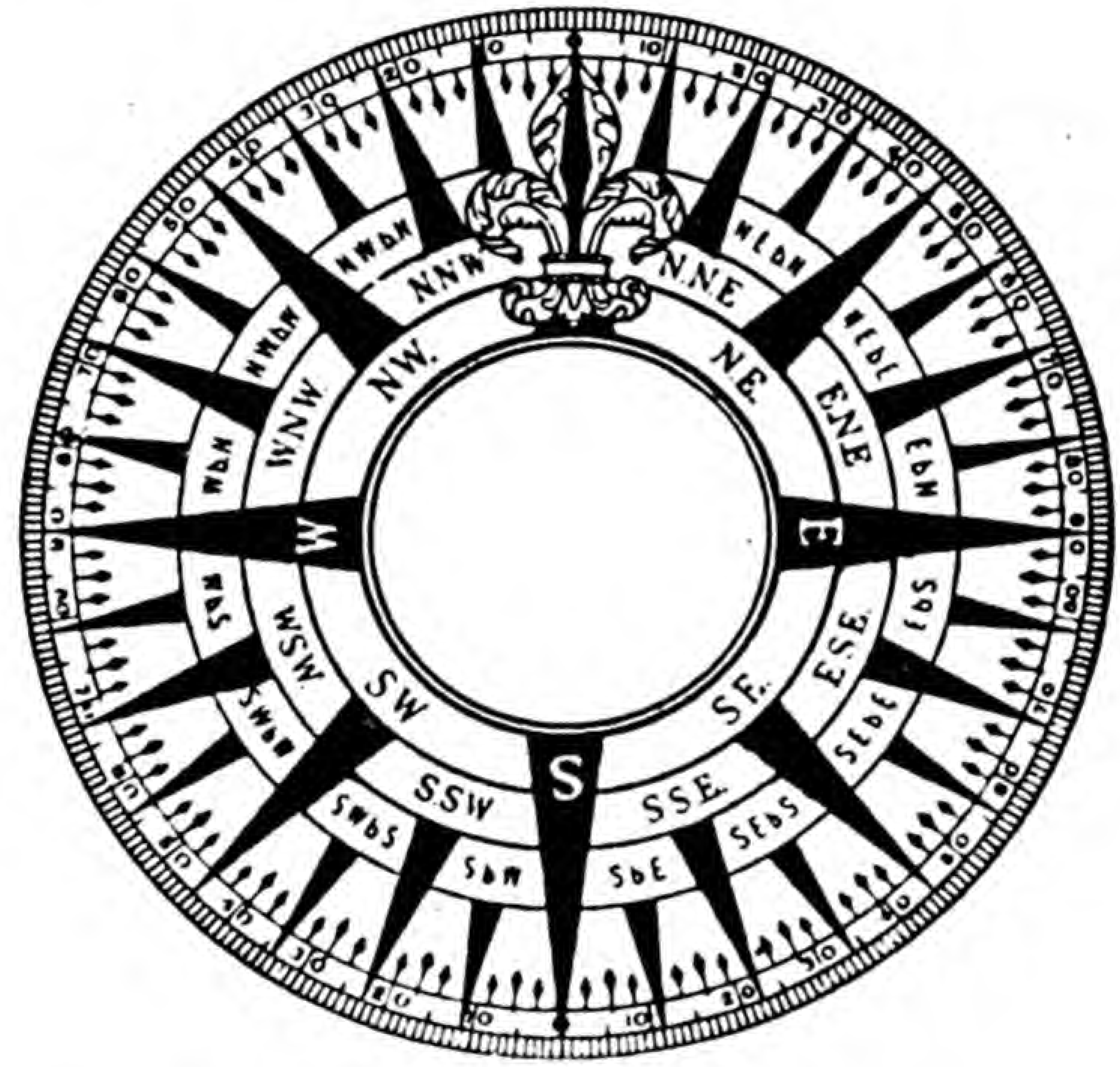


FIG. 62.—*The compass card.*

At the centre of the card is a metal thimble holding a jewel with a conical hole, which rests on the supporting pivot. A jewel, such as a small ruby, is used for pivots in the compass, in the best watches, and in the best pivoted electrical instruments, because it is very hard, and does not wear out. Underneath the card is fixed not one magnet, but eight,[1] as shown in Fig. 63, held by an

[1] The reasons why eight small magnets are better than one are rather too difficult to consider here.

arrangement of threads which makes the north point of the card point to the magnetic north. The whole card is mounted in a bowl, with a mark fixed close to the edge of the card which gives the direction of the bow of the ship. This mark is called the "lubber's point." Thus, if the ship is sailing due north the north point of the card will be at the mark, but if she is sailing west, since the

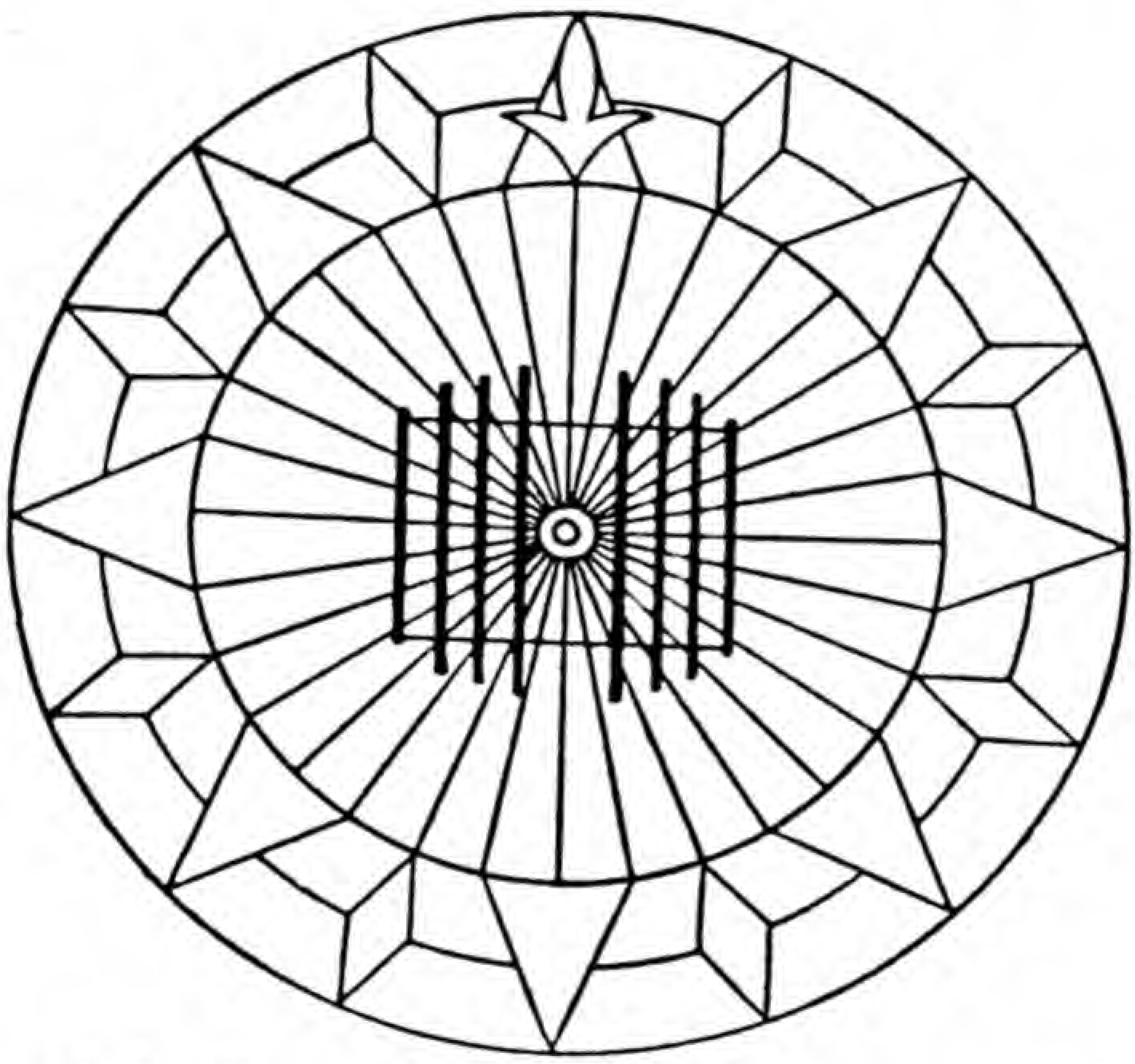


FIG. 63.—*The eight little magnets fixed underneath the compass card, with the pivot hole in the centre.*

north point still points north, the west point on the card will be opposite the mark. The bowl contains a liquid which buoys up the card, so as to take part of its weight off the needle, and also quickly stops any wobble of the card. So that the bowl shall not tilt to and fro with the motion of the ship it is mounted on what is called a gimbal, which can be best understood by looking at Fig. 64. The compass bowl is pivoted in the ring at A

and at a point opposite that does not show, because it is behind the bowl; and the ring itself is pivoted in the stand at B and B, so that, whichever way the stand tilts, the top of the bowl keeps horizontal. The whole stand which holds the compass is called a binnacle.

In old wooden ships the compass always pointed to the magnetic north, but practically all ships to-day are built of iron, which, of course, disturbs the compass, and disturbs it in a different way for different courses of the ship. It is possible to get over most of this disturbance

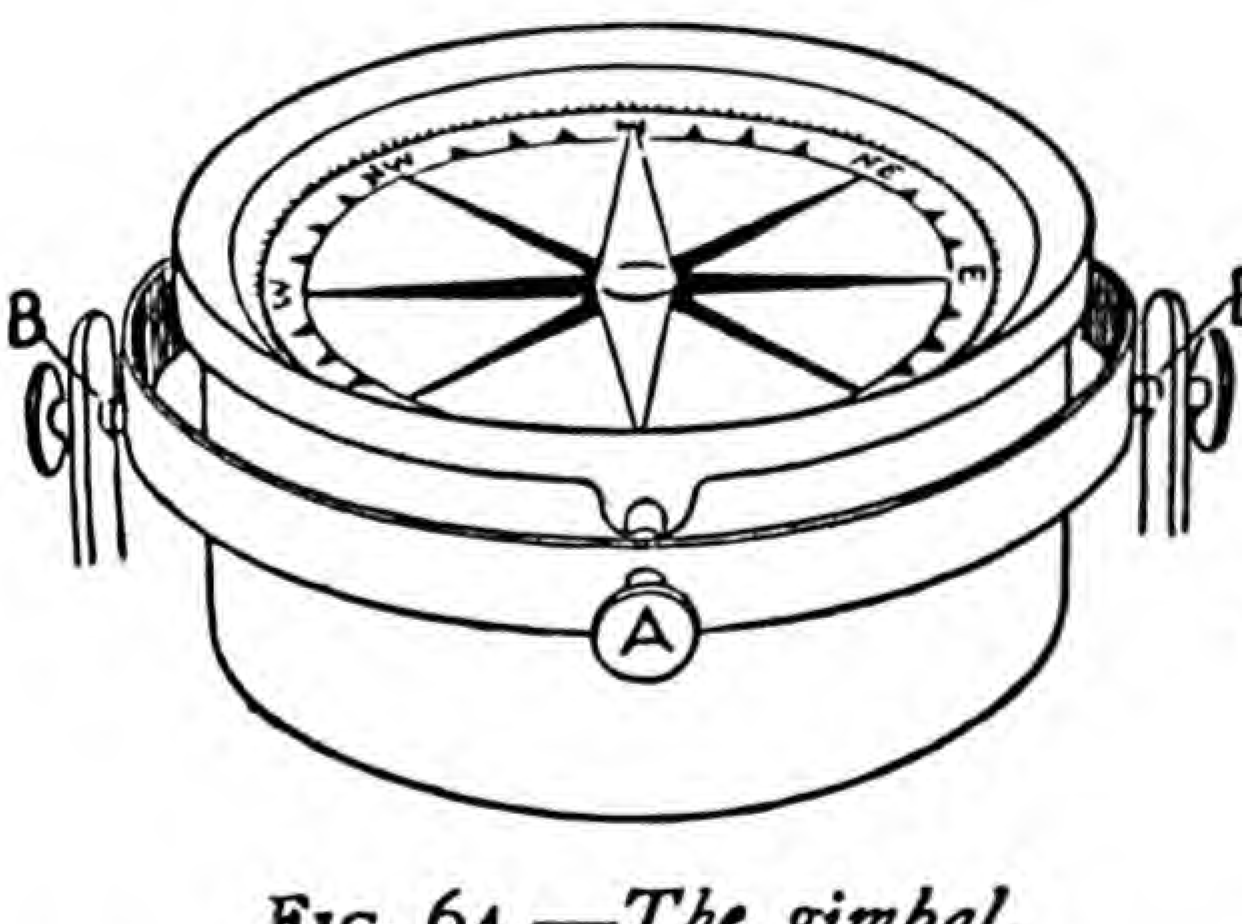


FIG. 64.—*The gimbal.*

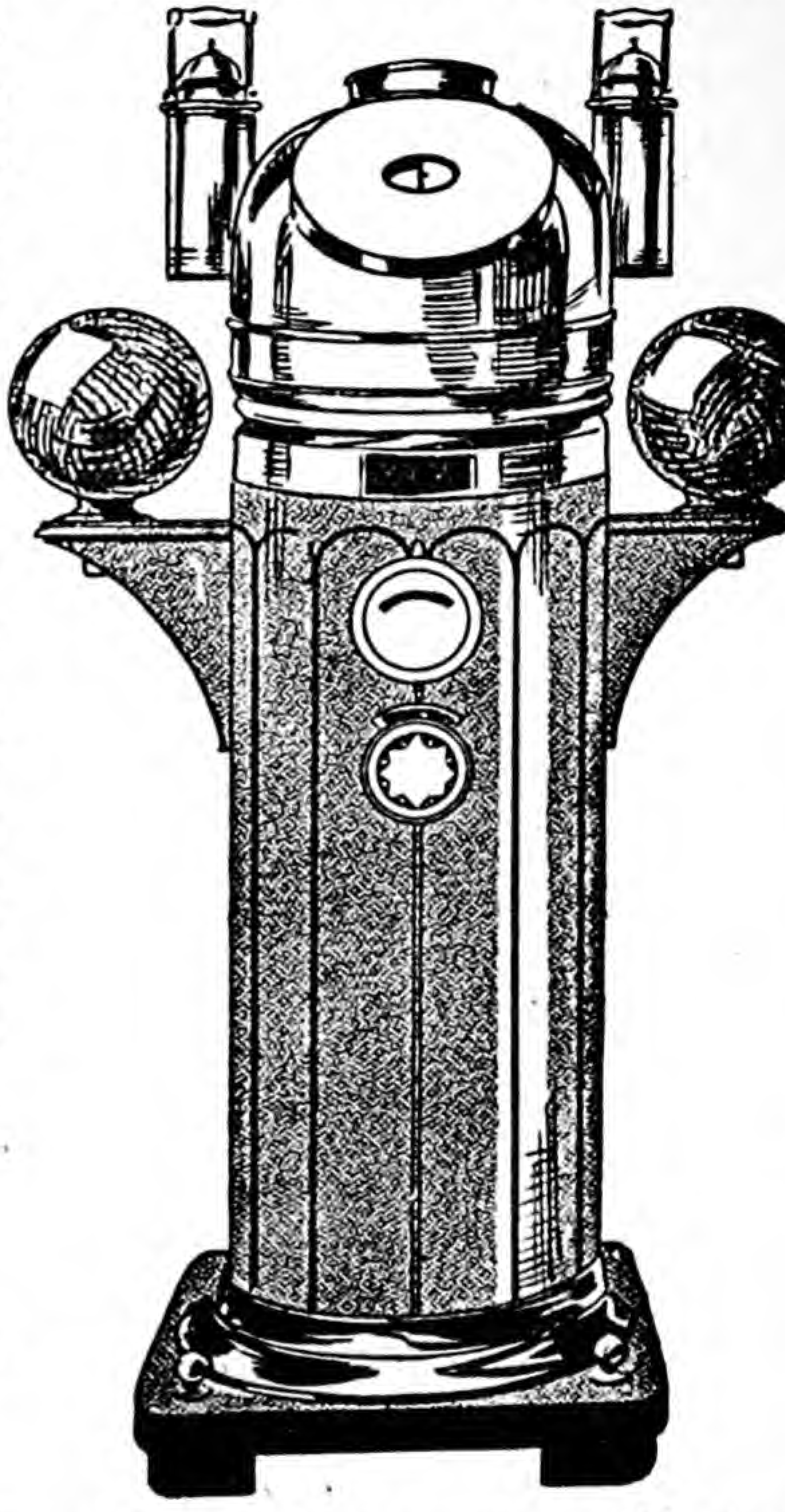


FIG. 65.—*A ship's compass. The two iron spheres are to balance out the effect of the iron ship on the compass. The compass card is seen by looking through the little window near the top.*

by having two hollow iron spheres arranged at a suitable distance from the compass, as shown in Fig. 65, and to balance out the rest of the disturbance by putting small

magnets and an iron bar in suitable places. You will see that a compass in an iron ship is not quite as simple a thing as a scout's compass, but careful calculations have shown how to make it point to the magnetic north. This is the kind of useful job which science enables us to do. The declination can be read off from the chart, and the sailor can then find the true direction in which the ship is sailing, day or night.

Electro-magnetic Induction

The long words electro-magnetic induction mean that a current can be produced, or "induced," as it is called, in a wire by a near magnet. This is one of the most important facts for the whole of our modern electrical engineering, both heavy electrical machinery, such as the dynamos which generate our household supply, and light instruments, such as produce our wireless music. Unless we clearly understand what the words mean we cannot hope to understand how any electrical machine works. The discovery of electro-magnetic induction was made by Michael Faraday in 1831, and it is so important that in 1931 a great celebration in honour of Faraday was held in London, at which men of science and electrical engineers from all over the world attended. Faraday made many other discoveries of the greatest importance, and in the Albert Hall there was a beautiful exhibition showing the wonderful things that had grown from his work. The most honoured thing in the whole show was, however, the old piece of iron, wound with wires and shabby insulating material, with which he first showed electro-magnetic induction.

We know that a current produces a magnetic force,

and have now seen several experiments to show this. After this had been discovered by Oersted in 1820 the question was naturally asked whether a current could be obtained from a magnet. The electric current produces magnetism; can magnetism produce a current?

A magnet placed near a circuit of wire containing a galvanometer certainly does not produce a steady current in the wire, as anyone can easily show. We know that a coil of wire produces a magnetic field, so that we might think it well to try whether one coil, carrying a current, induces a steady current in another coil near it. These were the kind of ideas with which Faraday started, but experiments on these lines had no success. A *steady* current does *not* induce any current in a circuit fixed to it. The experiment is mentioned to show the kind of thing that was tried before the way to induce currents was discovered.

The simplest way to show how electro-magnetic induction can be produced is as follows. We have a coil

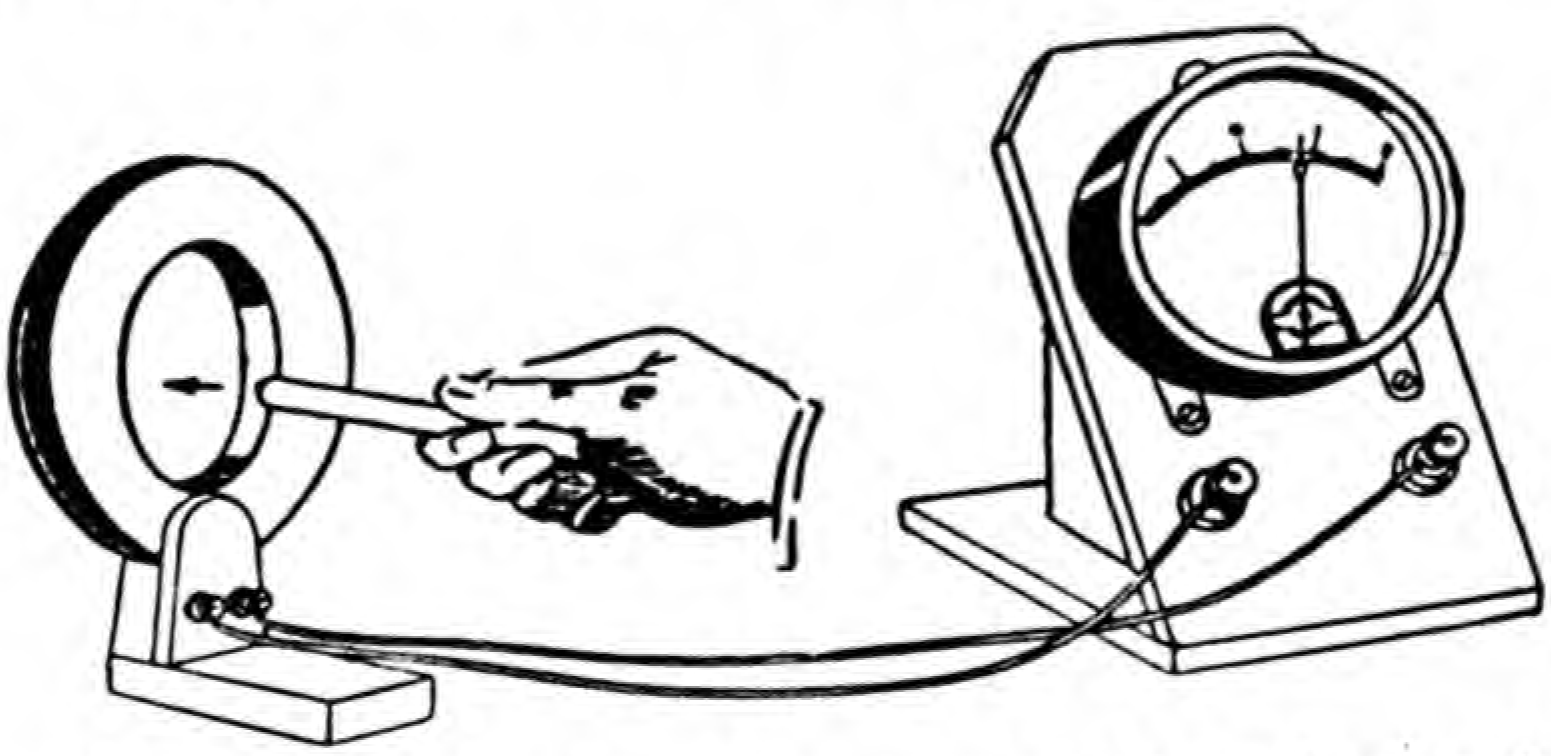


FIG. 66.—*Magnetic induction of current with coil on galvanometer.*

of wire connected to a galvanometer, standing well away from the coil, and a strong permanent magnet. If we bring the magnet up, and place it near the coil, we shall see that the galvanometer shows a small current, but as

soon as the magnet is placed at rest, however close to the coil, there is no current. If we take the magnet away there is a small current in the reverse direction. *It is the motion of the magnet that produces the current in the coil, not its mere presence.*

It is easy to carry this simple experiment a little further. If the magnet is pushed right into the coil, a bigger current is obtained; when it is pulled out a current of the same size in the other direction, as long as the magnet is moved equally quickly on both occasions. For—and here is another very important fact—the quicker the magnet is moved, the bigger the current. If the south pole is brought up to the coil, the current is in the reverse direction to that obtained when the north pole is brought up. Another pretty experiment is to place the magnet close to the coil, and pointing with its north pole at the hollow of the coil, and then to turn the magnet, without moving its centre, so that the south pole points that way. If it is turned quickly, a big current will be obtained.

Thus we see: (*a*) Any movement of a magnet near a closed coil of wire[1] produces a current in the coil.

(*b*) The quicker the movement, from one fixed place to another fixed place, the bigger the current.

(*c*) The direction of the current depends upon whether the magnet is brought up to, or taken away from, the given place.

(*d*) The direction also depends upon which pole of the magnet is nearer the coil when it is moved.

Now there is a general way of saying all this. We know that a magnet is surrounded by lines of force, the

[1] By a closed coil is meant one or more wide turns of wire with the two ends jointed, either directly, or by a galvanometer, which shows the current.

general run of which was made clear in our experiment with the filings. When we bring up a magnet we make some of these lines thread through the coil. It is found that the current depends upon the *rate* at which new magnetic lines of force are made to thread through the circuit. If this number of lines through the coil is made greater, as when the magnet is brought up, the current is in one direction; if the number is made less, as when the magnet is taken away, the current is in the other direction. Lines from near the north pole produce reverse currents to those from near the south pole.

We have shown how to get induced currents by moving a magnet near a coil, but we can also obtain induced currents by moving the coil, instead of moving the magnet. In fact, when we bring a coil up to a magnet we get just the same current as if we approach the magnet to the coil, if the rate of movement is the same in both cases. This is what we should expect; clearly, while we can cut a cake by moving the knife through the cake, we can cut it equally well by pushing the cake against the knife at the same rate. Or, instead of turning the magnet round on itself near the end of the coil, which, as we saw, produces a current, we can turn the coil round near the end of the magnet (Fig. 67). If we do this we get a current. It is, then, possible to get a current by turning a coil of wire in a magnetic field. This is the very simplest form of dynamo; but even the largest dynamos, by which engines of thousands of horse-power change mechanical energy into electrical energy, are built on the same principle. The magnet which produces the field in which the coil turns is called the field magnet.

In Fig. 67 nine different positions of a single coil of wire turning steadily in a magnetic field are shown, the

last position being the same as the first. From 1 to 5 the current flows in one direction, and from 5 to 9 in the other. The cross and the dot are to show the direction of the current: the cross is supposed to represent the feathers of an arrow going away from you, and the dot the head of an arrow coming at you. If, then, we keep on turning a coil, not too fast, a galvanometer in the

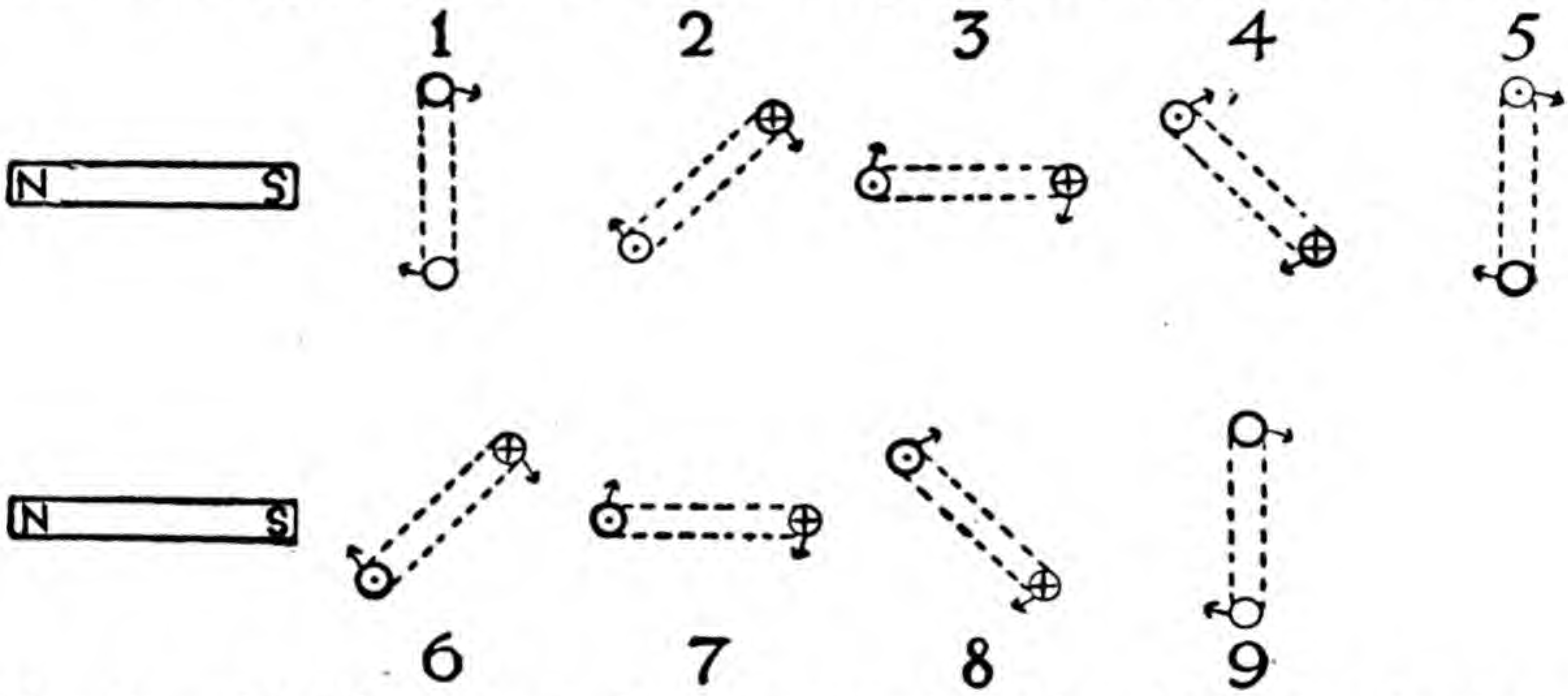


FIG. 67.—*To illustrate the flow of current in a ring of wire turning in a magnetic field. One section is drawn with a thicker line than the other, to make it easier to follow the turning. Between positions 4 and 6 the direction of the current reverses, there being no current just at position 5. The pictures show successive positions of a ring which is simply turning: there is, of course, no sideways movement.*

circuit will show a current first in one direction, then in the other, which is what is called an *alternating current* (often written just A.C.), while the ordinary current, always in one direction, is called a direct current (D.C.). If we turn it fast, then current will still alternate, but it will change direction too quickly for the galvanometer to follow it; before the moving part of the galvanometer has had time to move far in one direction the current is trying to turn it in the other direction. There are instru-

ments, however, that will follow the currents even if they alternate very fast. All the dynamos which are used today to generate electric power depend for their action upon the fact that the movement of a coil so as to cut magnetic lines of force will produce a current.

The way in which the very simplest type of dynamo works is illustrated in Fig. 68. Between the poles of a magnet, of the shape shown in the picture, there turns a coil of wire, arranged so that it can revolve in this space. When the coil is turned round it cuts the lines of magnetic force between the poles. If the ends of the coil are joined, therefore, we get an alternating current of electricity.

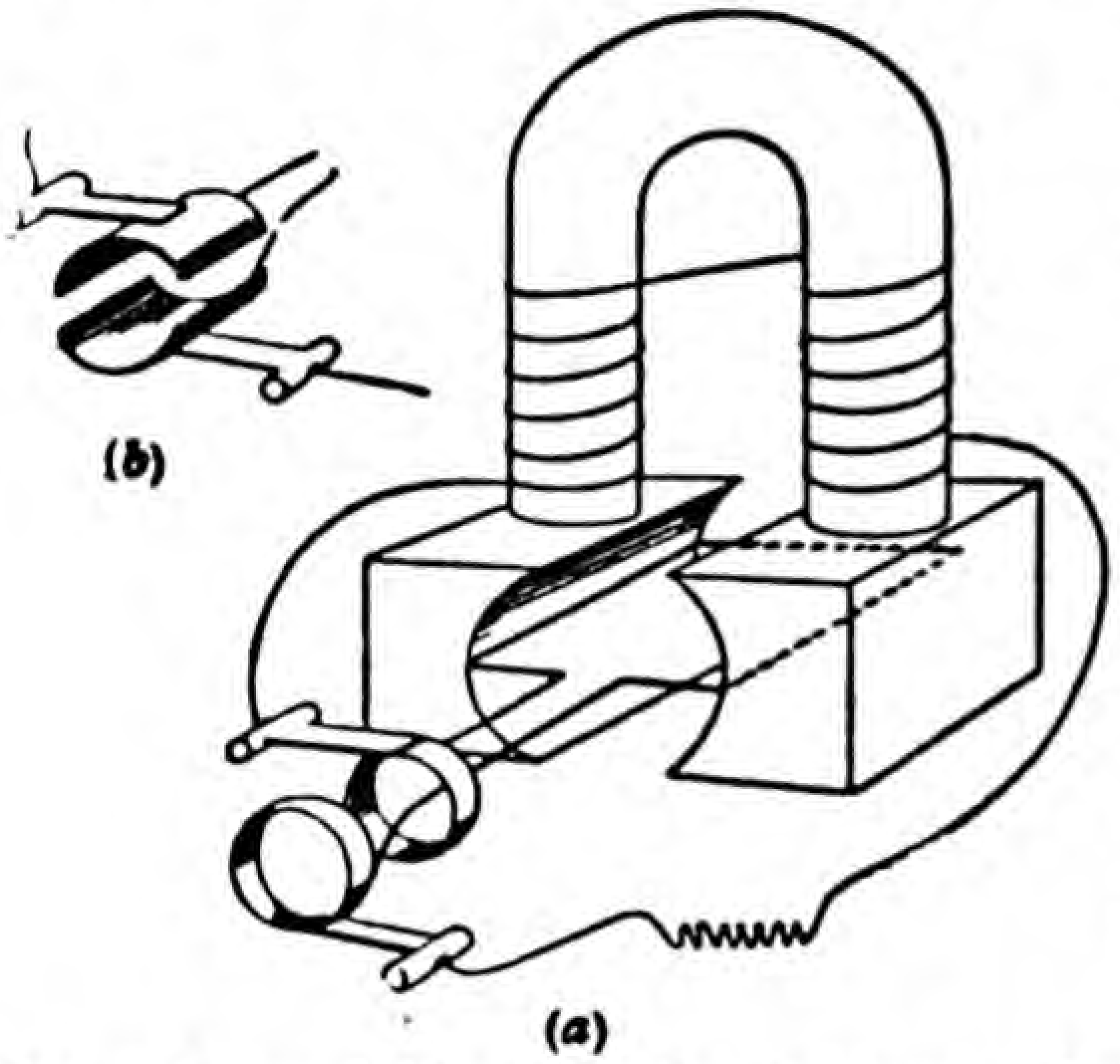


FIG. 68.—*The simple dynamo. In (a) the slip rings are for alternating current: the commutator for producing direct current is shown at (b).*

In any real dynamo the coil of wire would be wound on a cylinder of soft iron mounted so as to turn freely between the poles of the magnet. If the coil were not wound on iron, but on a wooden frame, we should still get a current. However, the iron cylinder, or armature as it is called, makes the magnetic force in the gap very much stronger, so that there are more lines of force to cut, and thus the current is bigger than it would be without the iron. In order that a current may be taken from the dynamo the ends of the rotating coil are fastened to two rings, fixed to the axis by insulating material,[1] as shown

[1] The insulating material is not shown in the figure, but only the position of the rings.

in Fig. 68 (*a*). Two pieces of metal, or sometimes of carbon, which are fastened to wires leading to the terminals of the dynamo, touch these rings and rub on them as they turn round, so that one end of the coil is always electrically joined to one terminal, the other to the other terminal. The rubbing pieces are called the *brushes* of the dynamo.

There is a clever device which is used if we want to draw direct current and not alternating current from a dynamo. It is a single ring, which is split, as shown in Fig. 68 (*b*), so that the two halves are insulated from one another. One end of the coil goes to each half of the ring. The result is that, as the ring rotates, first one end of the coil and then the other is electrically joined to one particular terminal. If the ring is so arranged that the change over takes place just as the direction of the current in the coil is changing, we shall clearly always have the current from the terminals of the dynamo flowing in the one direction.

The dynamos actually used are more complicated than this. For various reasons it is better not to have one, but several coils, wound on the armature. What the windings are like depends in the first place upon whether the machine is for direct or alternating current: for direct current if there are a very large number of windings, in different grooves in the armature, then the brush ring, or commutator (that is, changer) as it is called, is split into a large number of pieces, for there must be two pieces, opposite to one another, for the two ends of each coil.

The chief parts of a small dynamo are illustrated in Fig. 69: the fixed electro-magnet, or field magnet as it is called, since it produces the field in which the armature turns, is shown at (*a*), while the armature itself, with

twelve coils, is shown at (*b*). The commutator ring can be seen on the extreme right.

In large dynamos, built to produce alternating current, the armature, from which the current comes, is usually

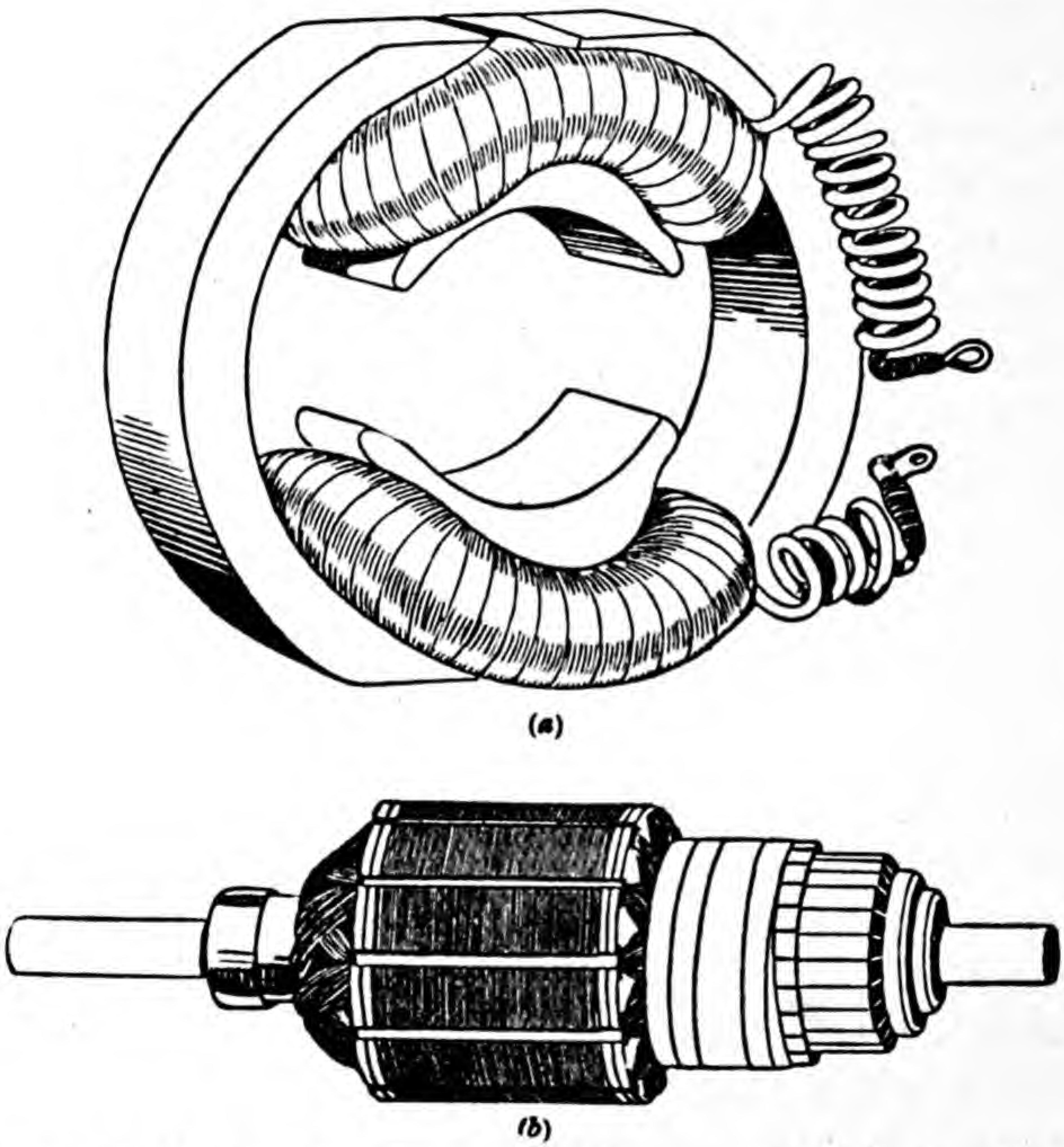


FIG. 69.—*The chief parts of a small dynamo.* (*a*) *is the field magnet, showing the two poles and the windings;* (*b*) *is the armature.*

fixed, while the magnetic field revolves. We can understand the principle of this by considering that if we move a magnet past a piece of iron, on which a coil is wound in the way shown in Fig. 70, the piece of iron will first

gain, and then lose, in magnetisation, so that a current will be induced in the coil. The dynamos illustrated in Figs. 71, 72 and 73 are all built on this principle. The construction is best understood from Fig. 72: all round the edge of the big wheel are attached electro-magnets, which can just be seen.

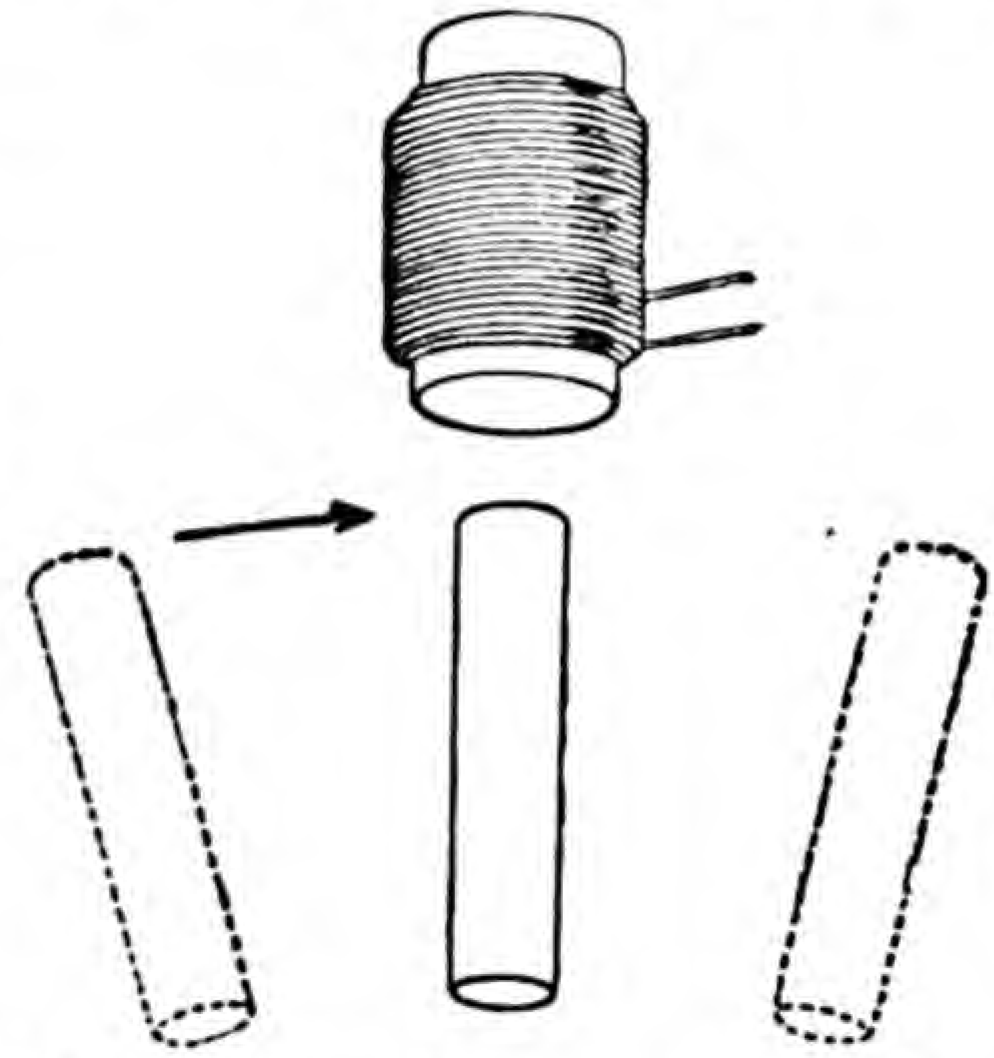


FIG. 70.—*A magnet moving past a piece of soft iron wound with a coil induces a current in the coil, because it makes the magnetisation of the iron vary.*

The design and appearance of dynamos for giving alternating current (or alternators, as they are generally called) depend upon the job which they have to do and the speed at which they are to be driven; for instance, the slower the speed the bigger the diameter of the armature. This is because, for a certain number of revolutions in a second, the bigger the diameter the bigger the strain on the armature. If an armature of great diameter were run very fast it would fly to pieces. If you swing a ball on a string, say at the rate of twice round in a second, you can easily convince yourself that the longer the string the bigger the pull on your hand. If the string is weak it may be quite strong enough to hold the ball when the string is short, but it will break if the string is long. In the same way the rim of a large wheel which is run very fast indeed will break away from the spokes and burst asunder.

A steam turbine does its best if run very fast; a Diesel engine runs slower, and a water turbine slower still. The

rotors[1] of alternating current dynamos, often called alternators, to be driven by steam turbines, which rotate about

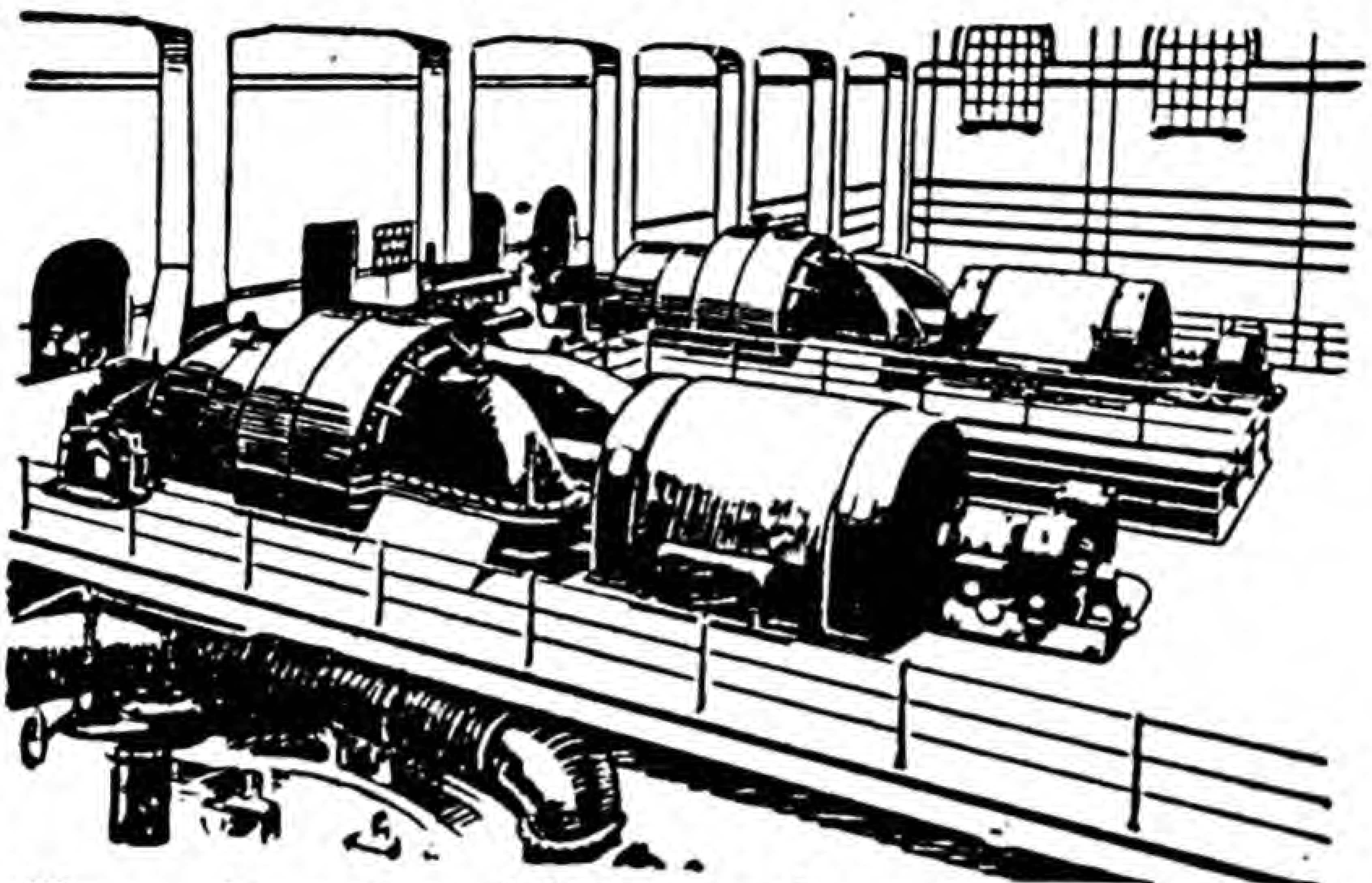


FIG. 71.—*Two alternators (dynamos for producing alternating current) in the Dalmarnock power station. The steam turbines which drive them are on the left, the alternators on the right. The diameter of the dynamos is small, because they have to run very fast.*

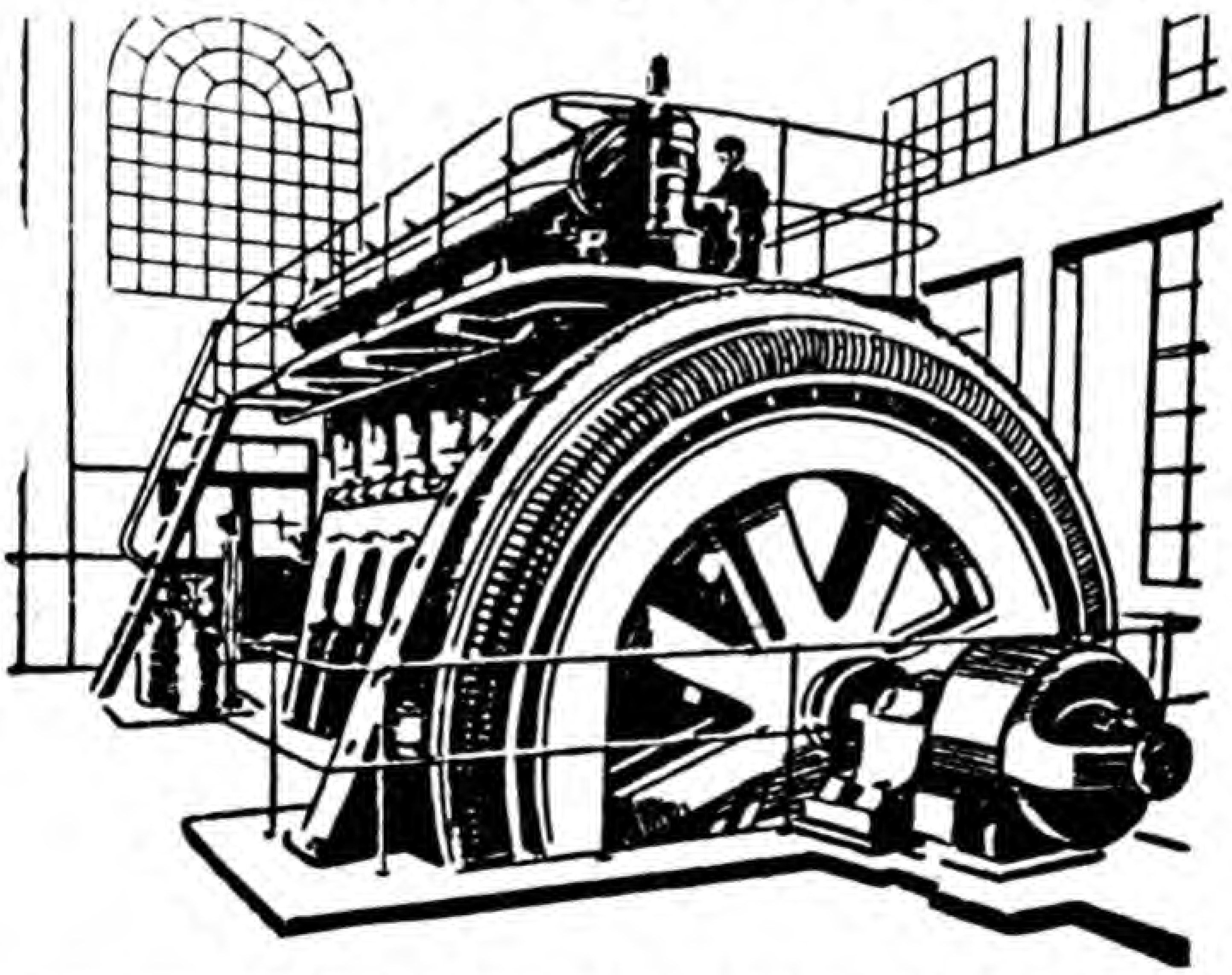


FIG. 72.—*An alternator in Japan, driven by a Diesel engine. The moving part is of medium size.*

[1] The rotating part of a dynamo is called the rotor. It may, of course, be the armature, but in most dynamos the electro-magnets revolve inside a fixed armature. We know that it does not matter if the magnet is moved and the wire circuits are fixed, or if the wire circuits are moving with the magnets fixed.

1,000 or more times per minute, are therefore small in diameter, not more than 5 feet, say, and very long; the

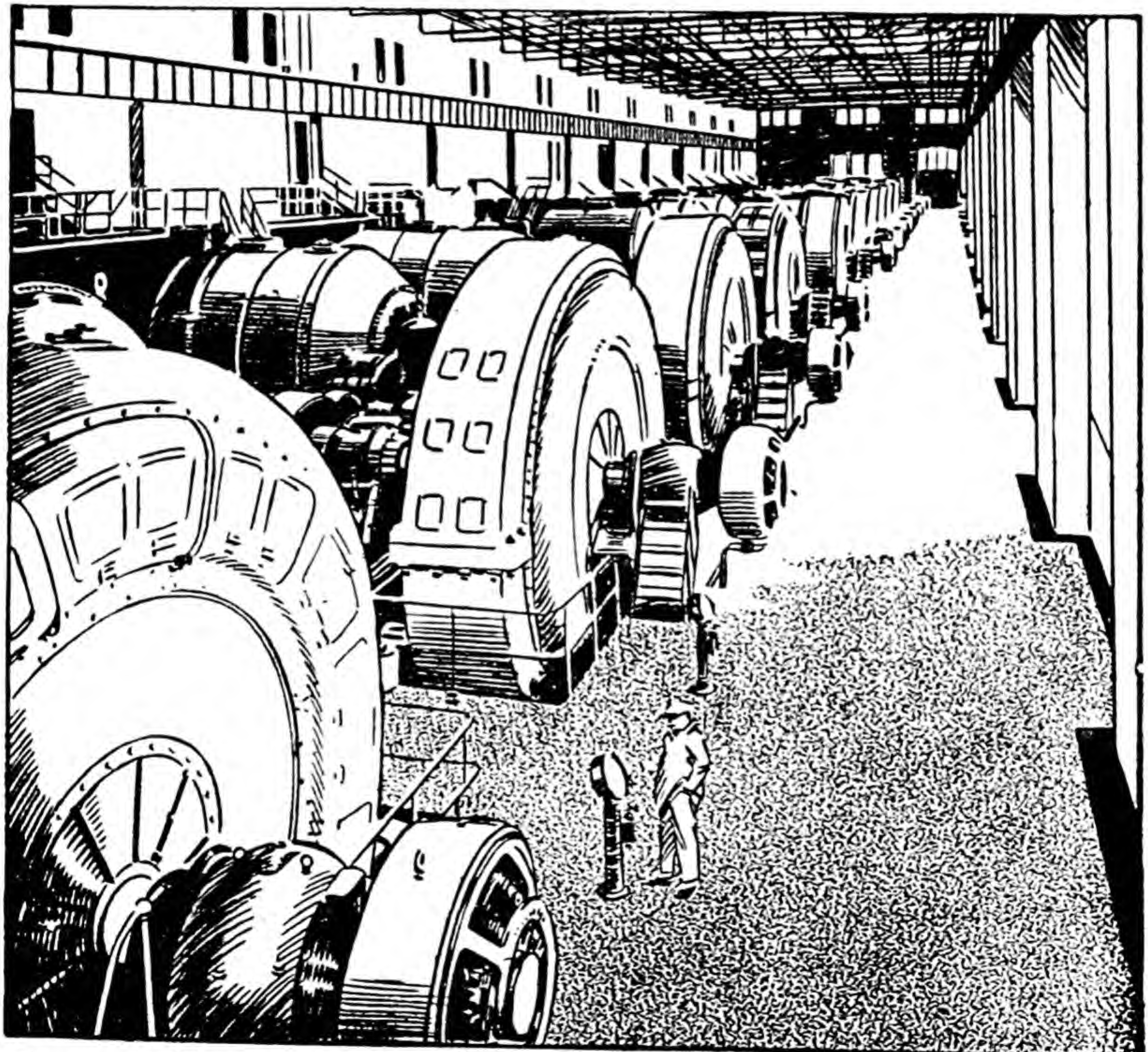


FIG. 73.—*Dynamos in the Trollhättan power station, Sweden. The diameter is very large, because the dynamos turn slowly, being driven by water power.*

rotors of alternators driven by Diesel or gas engines, which run at about only half the speed, may be about 10 feet in diameter; while the rotors of alternators to be

driven by water turbines, which revolve very slowly, are enormous, often 25 feet or more in diameter. The dynamos pictured in Figs. 71, 72 and 73 illustrate this point, and show the appearance of modern machines, such as are found in power houses.

We see, then, that Faraday's discovery of electromagnetic induction has shown us how to get electrical energy from a steam engine or a waterfall or any source of energy that we can harness to turn our dynamo. But why is so much energy required to turn a dynamo that

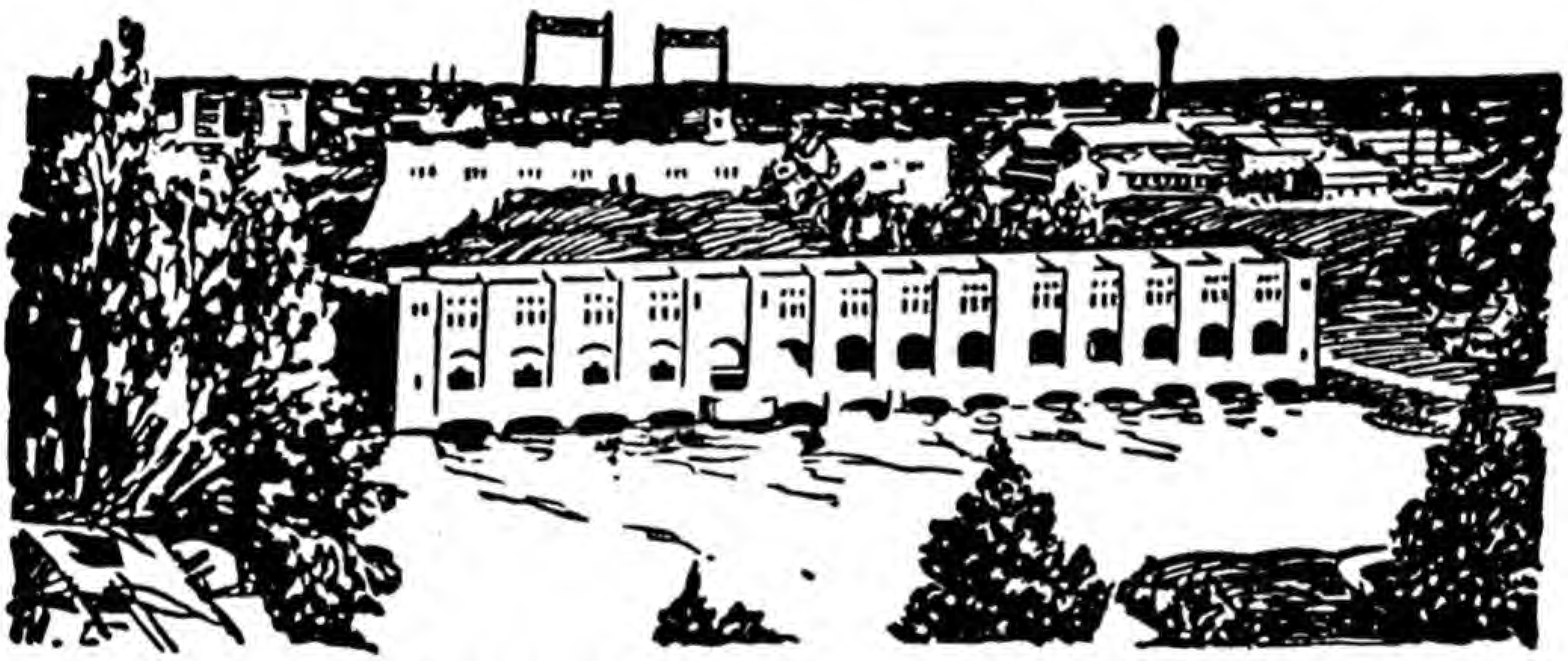


FIG. 74.—*Outside view of the Trollhättan power station.*

gives a large output of electrical energy? It might seem at first that, if the bearings were made very well, and properly lubricated, a very small engine would be sufficient to keep the rotor turning. This is perfectly true as long as nothing is fastened to the terminals of the dynamo. As soon, however, as the machine is wired up and we begin to take current out of it, more work is needed to turn it, and the more current we take the harder it is to turn. We might have expected this, for we learnt in Book I that we cannot get energy for nothing, but now we have to try to see why it happens.

Let us consider the armature in the simple dynamo of Fig. 69. When the dynamo circuit is open, as it is called, no current can flow round the armature coil. As soon, however, as we join them to a circuit and start taking current, this current flows round the circuit and through the armature coils, and the armature becomes a magnet: the more current we take, the stronger the magnet. This current flows in such a way that it is the north pole of the armature which is moving towards the north pole of the field magnet, which therefore repels it. Work has to be done, therefore, to push the north pole of the armature up to the north pole of the field magnet. Just as it passes, the current in the armature coil reverses, and we now have to take a south pole *away* from a north pole, which again requires work. This reversal of magnetic effect in the armature takes place, then, in such a way as always to oppose the turning. We cannot cheat the laws of nature, and get electrical energy without doing a corresponding amount of mechanical work.

People often think that if a dynamo is built under a railway carriage, with the armature on the axle of the wheels, we can get electric light on the train for nothing, so to speak. But what really happens? As long as we take no current the armature turns round freely, and the presence of the dynamo makes no difference to the train, but as soon as we start taking current the armature becomes a magnet whose poles always oppose the turning, and the carriage wheels turn with difficulty. We put a brake on, in fact, and the train either slows down a little, or the driver has to use more steam. We cannot get something for nothing.

We can, perhaps, make this even clearer if we go back

to our simple experiment of moving a magnet quickly up to a coil of wire. We seem to be getting a current from nothing. Actually, however, the current round the coil produces a magnetic force which tries to push the magnet away, so that it is a little more difficult to move the magnet up if the circuit is closed than if it is open, so that no current can flow. The force is so small, however, that the hand does not notice it, but then the current is small, too. When we move the magnet away the current, as we know, flows in the opposite direction so that the magnetic force which it produces tries to draw the magnet in, and once more opposes what we are doing. This is, in fact, a general rule. Whenever there is an induced current it always flows in such a direction that it acts against the movement which is producing it.

We know that a current produces a magnetic field and magnetic lines of force exactly like those of a steel magnet.

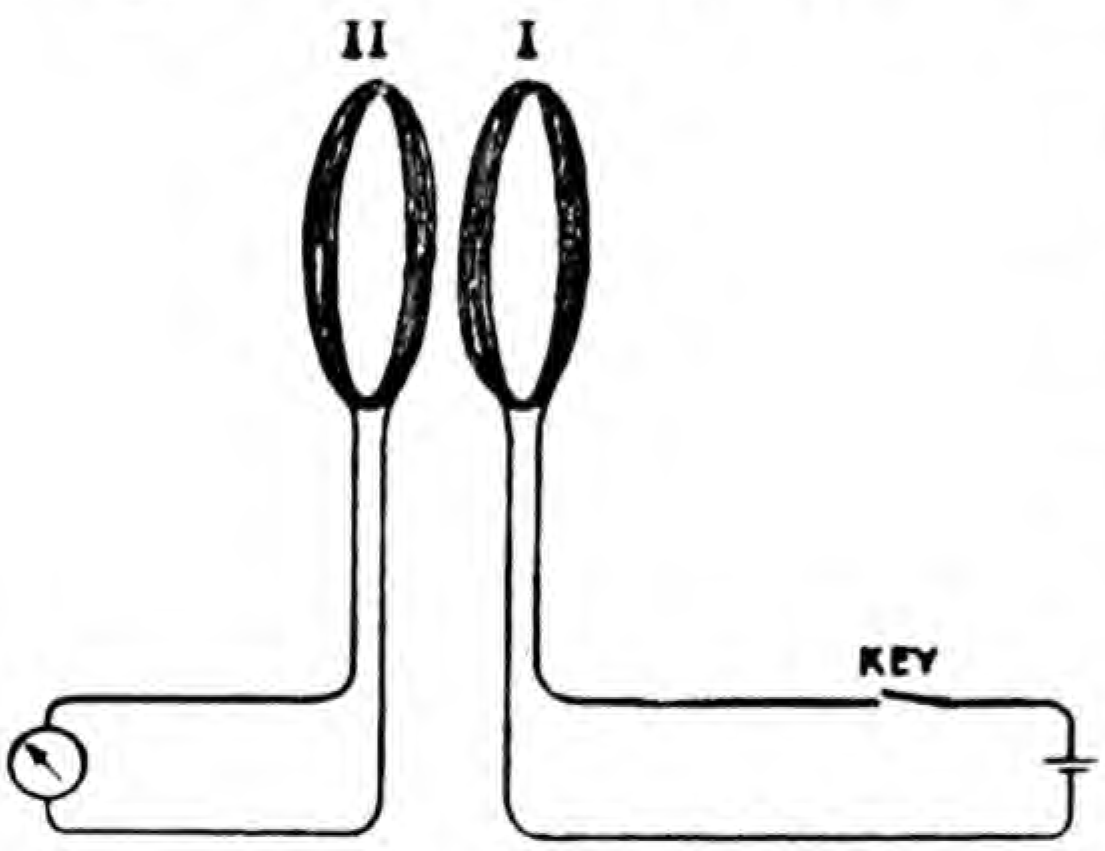


FIG. 75.—*Induction of currents.*

Suppose, now, that we have two circuits, I and II, facing one another, as in Fig. 75. If a current is flowing through the circuit I, lines of magnetic force will be threading through circuit II, but as long as there is no change in the current the number of lines does not change, and we know that it is only an increase or a decrease in the lines of force through circuit II that produces a current. The galvanometer needle, therefore, is at rest. A steady current produces no effect in a coil of wire near it.

Suppose, however, that we break the circuit I—that

is, that we stop current flowing in it, either by undoing one of the wires from the battery, or, better, by using the key, which is shown in the circuit. The lines of force produced by the current when it flowed in circuit I will, of course, vanish, and therefore the number of lines through circuit II will change rapidly, from something to nothing. A current will therefore flow for an instant in circuit II, while this change in the number of lines is taking place. If we close circuit I again, by joining up the wire, or putting down the key, we again get a current in circuit II, but this time, of course, in the opposite direction. Even if we only change the current in circuit I, by altering quickly a resistance in the circuit, the number of lines will change, and we shall get an induced current in II, but a smaller one.

If we stick a piece of iron through both circuits while the current is flowing in I, we increase the number of magnetic lines of force, and get an induced current. Or if, with the iron in, we break circuit I, we shall get a bigger induced current in circuit II than we obtained before.

We can now understand the way in which Faraday first showed induced currents. On an iron ring two circuits were wound, circuit I with a galvanometer, and

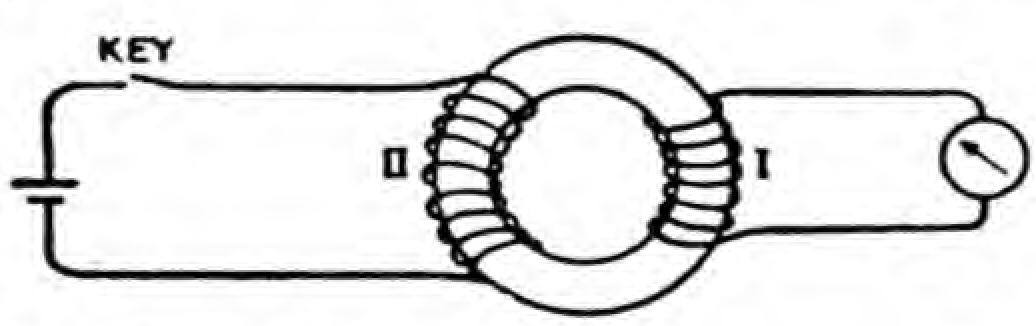


FIG. 76.—*Faraday's ring experiment.*

circuit II with cells and a key. If we put down the key and send a current through circuit I, the ring becomes a magnet, and we have a sudden jump in the number of

magnetic lines through circuit II, and a current passes for a moment through the galvanometer. If we keep the key down the magnetic force is steady, and no current passes. If we now break circuit I the magnetic lines through II disappear, and we have a current in the reverse direction to the former one.

If we pass not a steady but an alternating current through circuit I the magnetic lines go from strong in one direction down to nothing and then to strong in the other direction, and back again, or we say that the magnetic field alternates. It swings from side to side, like a pendulum, which is first to the right, and then passes through the position of rest (where it would hang if it were not swinging) to the left, and so on again and again. In consequence we get an alternating current in the second circuit. This is the principle of the transformer so much used in wireless sets. To consider why it is used would take us rather too far, but we can easily remember that it is another example of electro-magnetic induction. Whenever we have an alternating current in one circuit we can, in fact, get an alternating current in a second circuit by just putting it in a suitable position near the first, without joining the two circuits with wires, and we can increase the effect by using an iron core. Any changing current, or moving magnet, induces a current in a neighbouring fixed circuit. There is only one exception, that if the second circuit is arranged with its edge to the first circuit, or to the moving magnet, then, since no lines can thread the second circuit in either case, there can be no induced current.

Finally, we may say a word about the electric motor. This is a machine through which electric current is passed, with the result that an armature turns; this can be used

to do any kind of work, such as run a lathe or drive a train. An electric motor, then, simply is a dynamo reversed: with the dynamo we turn the rotor, and get current, while with the motor we supply current, and the motor turns. The same machine can be used for both purposes, although, for engineering convenience, there are generally small differences of design between machines intended to be used as dynamos and those intended to be used as motors. Why the armature rotates when the current is run through it can be easily seen by considering Fig. 68. The split ring shown at (*b*) is so arranged that the current produces a strong north pole in the armature when the place where the north pole comes has just run past the north pole of the magnet. There is consequently a repulsion which helps the armature on its way. The same thing takes place at the south pole. Every half-turn the armature receives a push in this way. The armature acts as a flywheel, and smooths out the pushes. In all actual motors there are many windings, just as there are in actual dynamos (see Fig. 69), and in consequence the push is divided up into several small pushes, which also smooths things out, and, in addition, makes for economical working.

CHAPTER IV

LIGHT

Light and Sight—Lenses—Reflection—Colour

Light and Sight

EVERYONE knows that it is on account of light that we are able to see things, but in ancient times extremely clever and learned men were quite wrong about the way in which vision takes place. For instance, most of the wisest thinkers of Greece and Rome believed that the eye sent out some kind of ray which touched whatever thing the man was looking at, and so gained knowledge of its shape and colour: seeing was, they believed, a kind of feeling by invisible feelers sent out by the eye, so to speak. We know now, however, that we see not by something sent out by the eye, but by something entering into the eye, and that something we call light.

The bodies we see may have the power of sending out light by themselves. A flame or an electric lamp or a glow-worm or certain kinds of rotten fish give out light by themselves, and are said to be self-luminous: if we take any one of them into a dark cellar, with no window of any kind, and shut the door we shall be able to see it. Most things that we see, however, are not of this kind. We see them because light, sunlight or lamp-light, falls on them, and they send back part of the light in all directions. Whether a body sends out its own light or borrowed light does not matter: we can see it only if it sends out light in some way.

We will now consider how this light behaves on its way to the eye from the spot from which it starts.

Light can travel through absolutely empty space, in which there is no air at all, as is clearly shown by the fact that we see the sun and the stars. For the light of the sun has to travel through about 93 million miles to us, and practically all of its path is absolutely empty, with no kind of gas in it; the stars are very much farther off, but the fact that we see them means that light from them travels to us. On the other hand, sound cannot travel through space where there is no air: if, for instance, there was an enormous explosion on the moon, which is much nearer to us than the sun, we should not hear anything, although we could see the flash.

The light which comes to our eyes from things on the earth has, of course, travelled through air, and not through empty space. The air, and especially the dust in it, weakens the light from far-off objects, such as distant hills, and makes them look misty. After a shower of rain, which washes the grains of dust out of the air, everything in the countryside looks much sharper and clearer, but even clear air has a small effect on the way in which light travels. For all ordinary experiments in rooms the difference between the behaviour of the light travelling through the air and light travelling through empty space is far too small to trouble us. Astronomers, however, who have to deal with light which, after travelling from heavenly objects through empty space, enters the coat of air which surrounds the earth, have to make certain allowances for the effect of the air in slightly changing the direction of the rays.

Since we can only see a thing if light from it enters our eye it is impossible to see from the side a beam of light, how-

over bright, that travels across a dark room and enters, say, a dark hole lined with black velvet, which completely absorbs it. "But," you will say, "it is easy to see a beam of sunlight on a summer's day coming through the fanlight of a hall, say, or a searchlight beam at night, although neither enters the eye, but is seen from the side." It is quite true that it is easy to see the path of a beam of light under these conditions, but this is because the air contains little particles of dust which throw a small part of the light out sideways from the beam, so that it reaches the eye. Every floating speck of dust in the beam thus acts as a tiny source of light, and shows us where the beam is passing. If we make extra dust, by shaking a chalky duster in the path of the beam, or if we blow smoke across it, the path will become brighter: if we could get rid of all dust we should not be able to see the path at all.

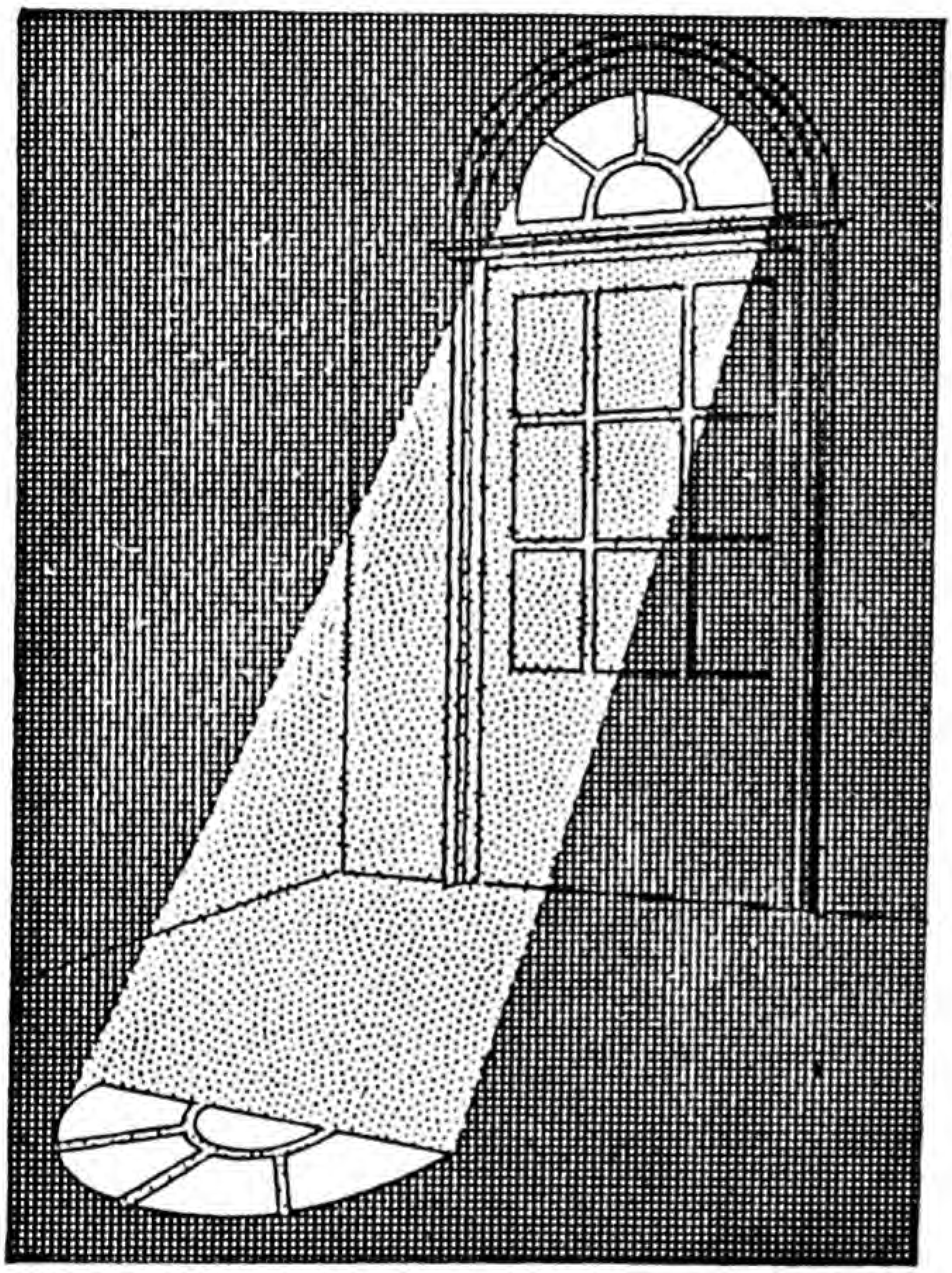


FIG. 77.—*A beam of sunlight in a hall is visible because the dust scatters the light sideways to our eyes.*

This can be shown by means of a box with a glass front, the other sides being blackened. At two opposite ends are holes, with glass windows, to allow a beam of

light to pass through the box. The walls of the box are wetted all over with glycerine; this is a very sticky liquid, which holds any dust particle that settles on it. It is best to leave the box for some days before the experiment, so as to give every dust particle a chance of being caught. If a strong beam of light, say a beam from a projection lantern, or a beam of sunlight reflected by a mirror, is sent through the box it will be clearly seen outside, but quite invisible where it passes through the dust-free air. If a little smoke is blown into the box the beam at once appears, as shown in Fig. 78. It is useful to remember that, if we want to see plainly the path of a beam of light, smoke or chalk dust shaken from a duster will reveal it to us.

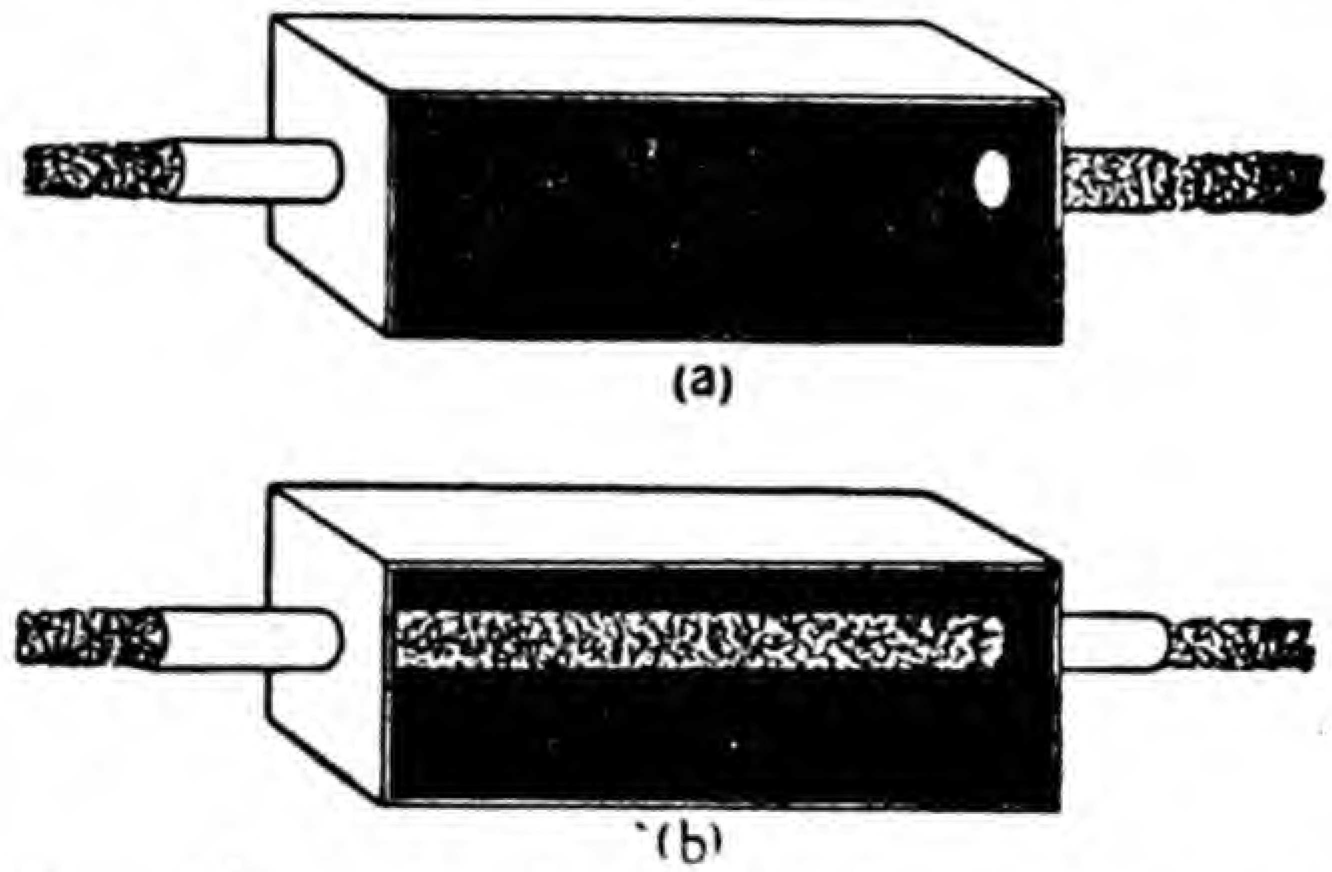


FIG. 78.—(*a*) *A beam of light passing through dust-free air is invisible from the side, but* (*b*) *becomes visible if a little smoke is put into the air.*

Light travels in straight lines. If, for instance, we take a lamp and we arrange three slits, cut in tin, so that we can see the light of the lamp through them, it will be found on testing them with a straight piece of wood, such as an ordinary metre scale, that they are in a straight line.

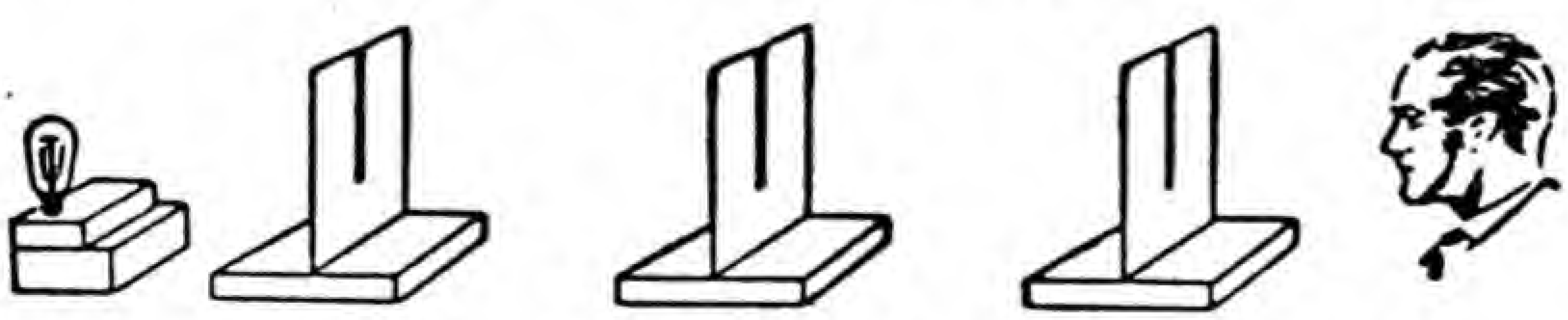


FIG. 79.—*Light travels in straight lines.*

We must not, for this argument, test if our piece of wood is straight by looking along it, of course, for if light did not travel in straight lines this would be no test of straightness, and if we start by knowing that light does travel in this way, there is no point in doing the experiment with the slits. We can, however, test our wooden rules for straightness, if we have three of them, by laying them edge to edge, two at a time. If, in all cases, they fit well together they must be straight. If only two fit together it does not prove that they are straight, even if they will rub on one another without showing a gap in any position, for both edges might be portions of large circles, as shown by A and B in the picture. The rule C may also fit on A, and still neither be straight, as shown, but if they are not straight we shall see it at once when we try to fit B on C. When we are convinced that light travels in straight lines we can, of course, test a rule for straightness by holding it to the eye, and looking along it, as carpenters do.

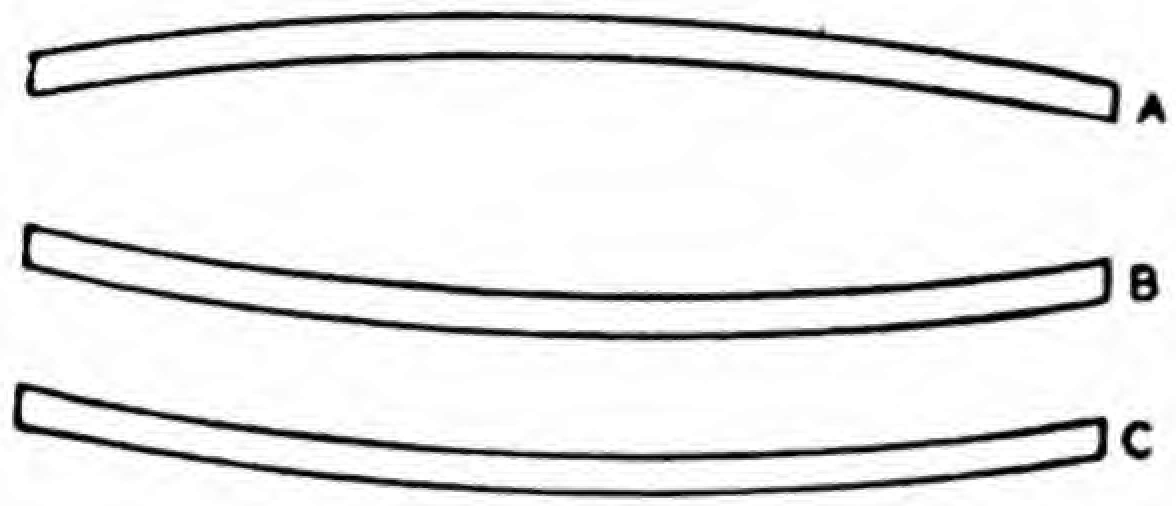


FIG. 80.—*If three wooden rules all fit edge to edge on one another they must all be straight. The upper edge of each rule is supposed to be the one to be tested.*

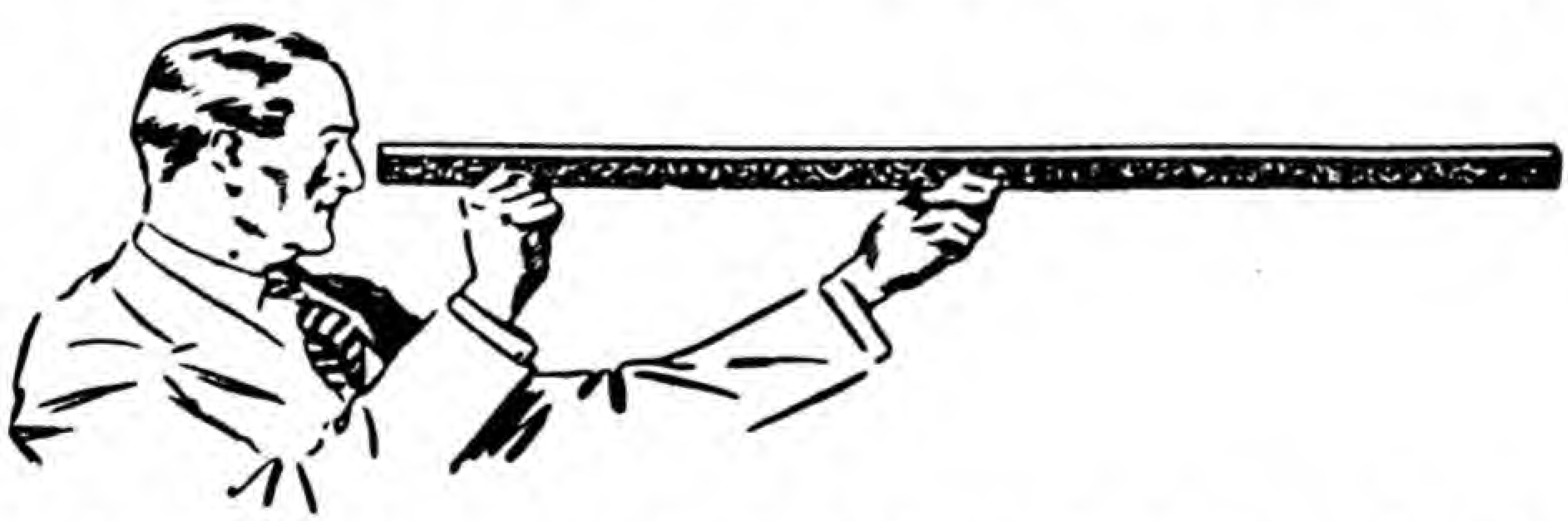


FIG. 81.—*Testing a rule for straightness by looking along it.*

We can also show that light travels in straight lines by means of shadows. To get a sharp shadow we require a rather narrow source of light. A candle flame will do, but we get a better source if we surround a lamp with a cylinder, such as a round tin with the bottom cut off, in which a slit is cut. The straight edge of a piece of wood placed in the path of the light from the slit will throw a very sharp shadow, and with our rule, or with a tightly stretched thread or fine wire, if the distance is too large, we can show that slit, edge of wood and edge of shadow are in a straight line.

Shadows give very interesting examples of the paths of light rays. A rod of wood throws a very sharp shadow by the light from a slit. If, however, instead of a slit we use a larger source, such as an electric lamp surrounded by a cylinder of tissue paper,[1] we shall get a dark line of shadow, with pale shadow on each side. The reason is clear. Light comes from every point of the source; the light from A throws a sharp shadow ST, and the light from B throws a sharp shadow UV (Fig. 82). The only part protected from all light is where these shadows overlap—that is, SV. The part US, which is protected from light from B, receives light from A, and other parts of the source, and so is only a half-shadow, and VT is only a half-shadow for a similar reason. If the source of light is larger than the object, as shown in Fig. 82*b*, then it is clear that while on the near side of C, as at D, there is a perfect shadow with half-shadow borders, beyond C, as at E or F, there is no complete shadow, but only a washy half-shadow. Shadows of things the size of your body thrown by the sun on a

[1] In the case of an oil lamp a cardboard screen can be used, with a wide opening cut in it which is covered with tissue paper.

near wall are dark, with a very narrow half-shadow border. A pencil in sunlight, held about a yard from a wall, will give about equal dark shadow and half-shadows, something like Fig. 82*b*. You should draw these cases, remembering that the sun is so far off that two rays from A are practically parallel.

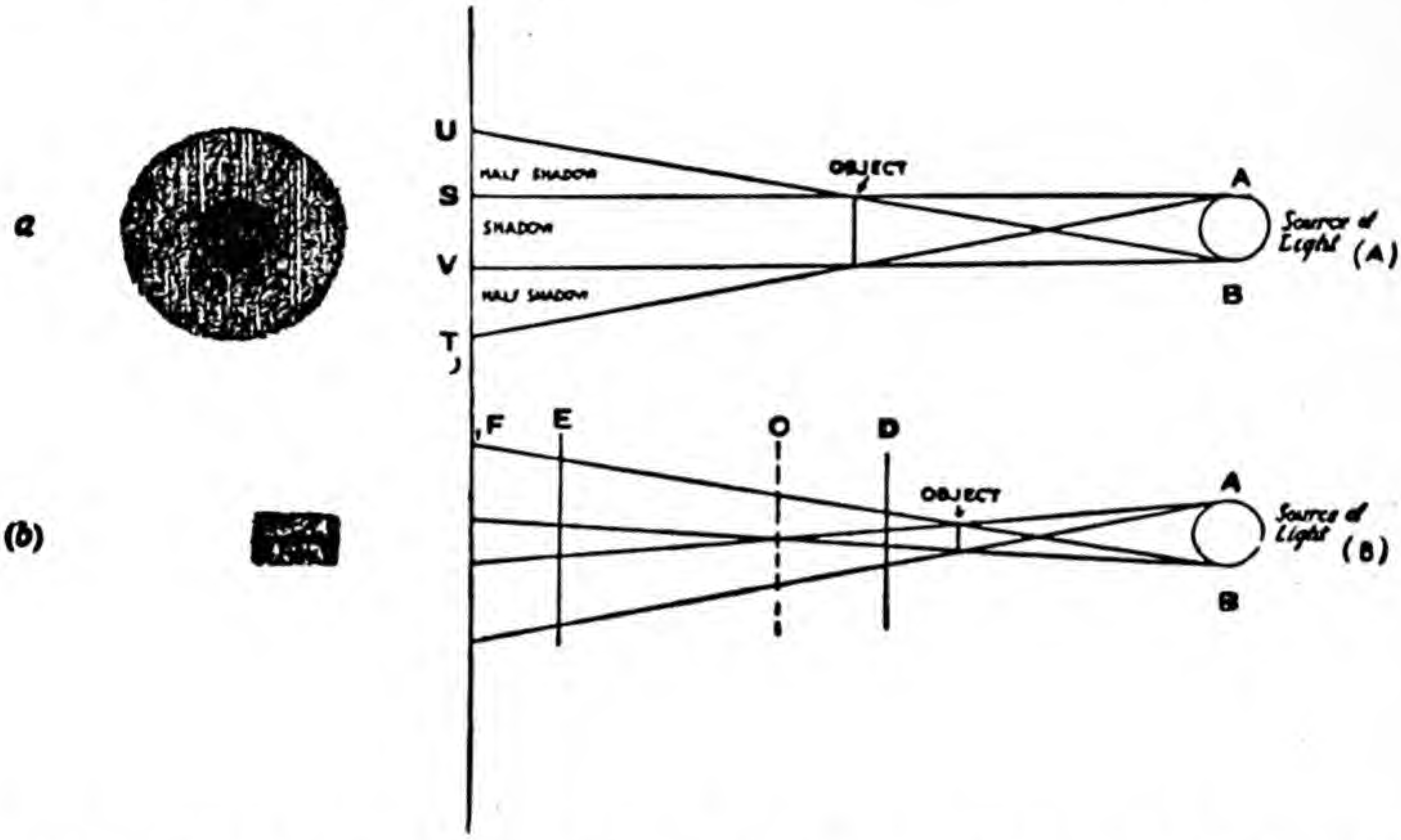


FIG. 82.—*Umbra and penumbra.* (*a*) *Shadow of a round object thrown by a source of equal size;* (*b*) *shadow with a source wider than the object. The upper shadow drawing shows the shadow of a round object on a screen placed at UT: the lower shadow drawing shows that of a stick on a screen placed at D.*

The dark shadow which receives no light at all is called the *umbra*, and the half-shadow the *penumbra*.

A very interesting case of shadows is given by the heavenly bodies. Sometimes the moon passes just between the sun and the earth, cutting off all or part of the sun's light, and this is called an eclipse. It so happens that the moon just about makes the same angle with the eye as the sun does, the extra size of the sun being balanced out

by its greater distance.[1] Either the one or the other is just about covered by a small pea held at arm's length. It is clear, then, from Fig. 82, that there will only be a narrow region on the earth which is in complete shadow when the moon passes right between earth and sun, and on either side a region of pale shadow. The narrow region where the eclipse is complete moves over the surface of the earth as the sun moves, tracing out a thin band which is called the region of totality. Within this region of totality an eclipse of the sun is a very striking experience. If the sun is shining brightly before the eclipse the rapid approach of darkness as the moon moves over its face, and the sudden cold as complete darkness comes, impress not only man but the animals. The birds seem scared, and fly low, and there is a hush over the countryside. It is no wonder that in ancient times, when their causes were not understood, eclipses were supposed to be the sign of some coming disaster. Milton, speaking of the sun, says magnificently:

> " or from behind the moon
> In dim eclipse disastrous twilight sheds
> On half the nations, and with fear of change
> Perplexes Monarchs."

You will often see strange shadows due to two or three lights hung at different places, but if you remember the travelling of light in straight lines you will generally find

[1] The diameter of the sun is 886,000 miles, and its average distance from the earth about 93,000,000 miles; the diameter of the moon is 2,160 miles, and its average distance 224,000 miles. Now $\frac{886}{93{,}000} = \frac{95}{10{,}000}$ and $\frac{216}{22{,}400} = \frac{97}{10{,}000}$, which is nearly the same. The distances of both sun and moon from the earth are not always exactly the same, so that these figures change slightly from eclipse to eclipse.

it easy to explain them by the overlapping of different regions of light and darkness due to the separate lights.

Now let us consider the passage of light through a small hole, say a large pinhole in a piece of thin tough card or in a piece of stout tinfoil. Suppose that the source of light is an electric lamp—a candle flame will do if electricity is not at hand. The light from the point A, passing in straight rays through the hole H, will make a tiny patch of light, of the same shape as the hole, but

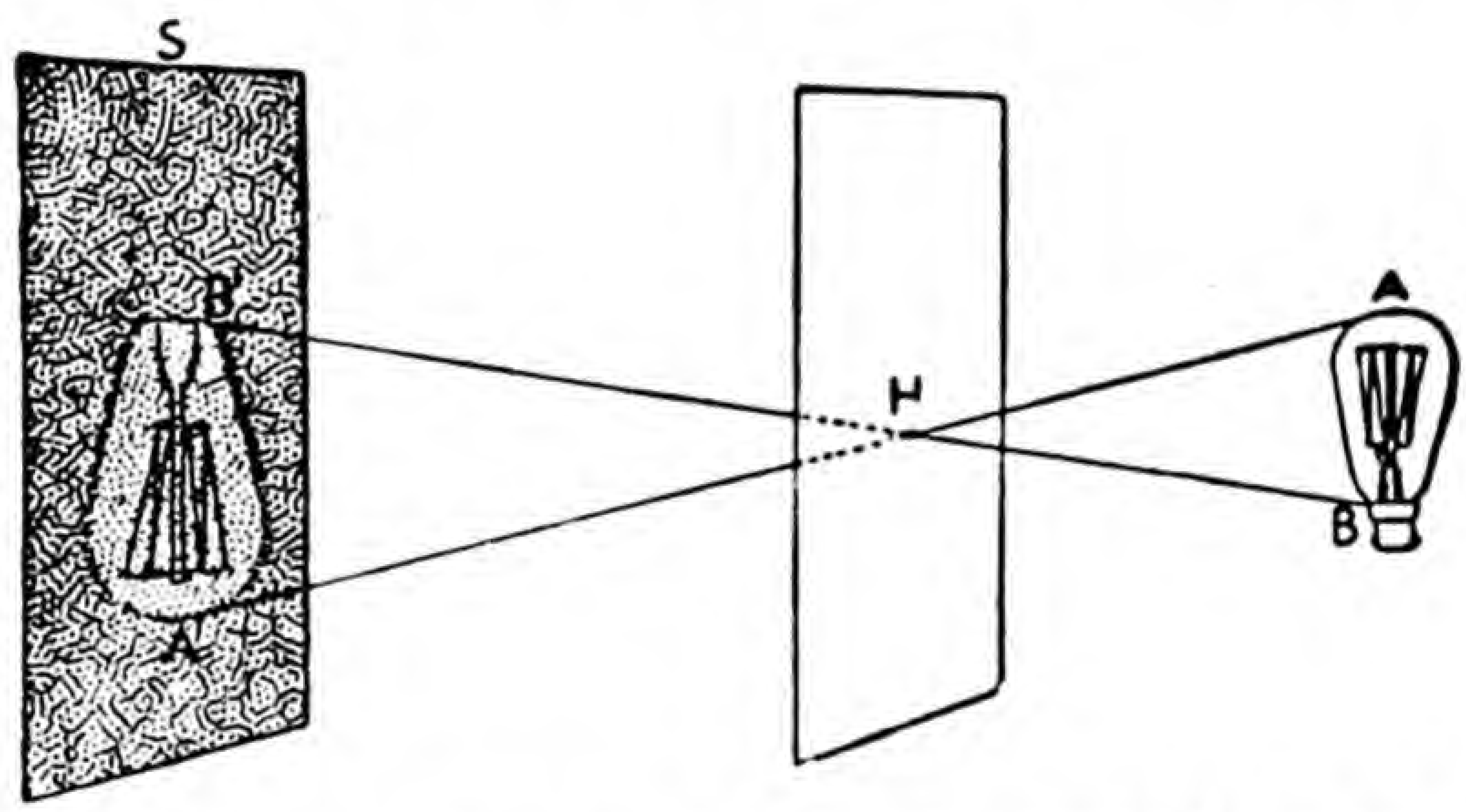


FIG. 83.—*The image of an electric lamp formed by a small hole, H, in a screen.*

somewhat larger, at A′, on a screen of white cardboard placed at S. The light from the point B will form another little patch at B′, and every other bright point of the lamp will likewise be represented by a little patch of light. It is clear, then, that we shall get a picture, or image as it is always called in the science of light, of the lamp on the screen, made up of tiny overlapping patches of light. The image will be upside-down, and reversed left to right, as appears from Fig. 83, from which it can also be seen that if the screen is nearer to the hole

than the lamp is, the image will be smaller than the real lamp, but if the screen is further from the hole than the lamp, the image will be larger.[1] The way in which the image is formed is a further proof that light travels in straight lines.

It is interesting to notice that the fact that a good image is formed shows that rays of light pass through one another without getting in one another's way at all, for all the rays go through the small hole, and it can easily be shown by covering up part of the lamp that the image of any piece of the lamp is just as good when all the rays are passing through as when only those necessary for the small part go through.

As every tiny point of the glowing wire forms not a point, but a small patch in the image, the image will not be quite sharp. As long, however, as the hole is small the patches are small, and the image will not be badly blurred, and it also does not matter what shape the hole is. An image made up of small overlapping triangles, formed by a triangular hole, looks very much the same as an image of the same object made up of small overlapping discs. A very interesting example of this can be seen under any tree on a bright summer day, when the sun is shining without cloud. The ground will be found to be covered with little patches of light among the shadow, which the poets call a "dappled shade." These little patches are mostly round, although clearly there are no round holes in the leaves. They are, in fact, images of the round sun caused by holes, or chinks, of irregular shape

[1] This kind of experiment with light must be done either after dark, or in a room darkened by pulling down the blinds, say, or there will be too much light from other directions falling on the screen for the image to be clearly seen.

left by the overlapping leaves, and are round because the sun is round, as shown in Fig. 84. As long as the chink is small, its shape does not matter. In a partial eclipse, when the sun is partly covered by the moon, and so shows a crescent shape, the patches of light in the dappled shade are crescent-shaped and not round, which gives a very curious appearance.

Fig. 84. — *How the chink between leaves forms a round image of the sun.*

Of course, if the hole or gap is large we get merely a patch of light the same shape as the hole, but rather fuzzy at the edges. Each point of the bright source of light now forms a very large patch of light on the screen, and the large patches formed by the different points overlap nearly completely.

Lenses

We have seen how a small hole can form a pretty good image of a bright object. Suppose, then, that we have a dark room, the windows being closed by shutters, in one of which is a small hole, and that the sun is shining on the scene outside, so that from every point of it light is streaming away. On the opposite wall of the room a picture of this scene will be formed by the hole, upside down, of course. Suppose, instead of a room, we take a box with a small hole in one side, in a similar way an image of any bright scene can be formed on the opposite side. If we put a photographic plate against this side we can take quite a good photograph with such a box, which is called a pinhole camera. You know, however, that such

a camera is never used, but one with a lens, instead of a pinhole. Before we can see quite clearly why this is we must consider what lenses do, and to understand lenses we have to learn how light behaves when it passes from air to glass.

A ray of light that goes from air to glass, or from air to water, or to any other transparent[1] substance, is bent at the surface; that is, it travels in a straight line in the air and in the glass, but the two straight lines make an angle with one another, as shown in Fig. 85. One of the best ways in which this can be shown is by using a lantern that will throw a strong beam. The path of the beam in air can only be made visible by a little smoke, as described on p. 117, and the path in the water shows up if a glass-sided tank is used, and a little red ink put in the water, which, strangely enough, makes it shine green where the light passes through it. In passing from air to water the light is bent so as to make a smaller angle with the line AA, which is at right angles to the surface of the water. A line at right angles to a surface is said to be *normal* to it, so that this rule is often put in the following way: in passing from air to a denser substance the light is bent towards the normal to the surface. Of course if the ray passes from the denser substance to air it is bent in the reverse direction, away from the normal, as can also be seen from Fig. 85. We have only to think of the ray starting at the bottom of the tank, and going to the lantern, as it would

[1] A substance like glass through which light passes without interruption, and so through which you can see, is called *transparent*, while a substance like iron, which does not let light pass through it, is called *opaque*. A substance like ground glass, which lets light through but scatters the light in all directions, so that you cannot see through it, is called *translucent*.

if we put a little piece of mirror in the water at right angles to the beam. The ray is bent away from the normal when it leaves the water.

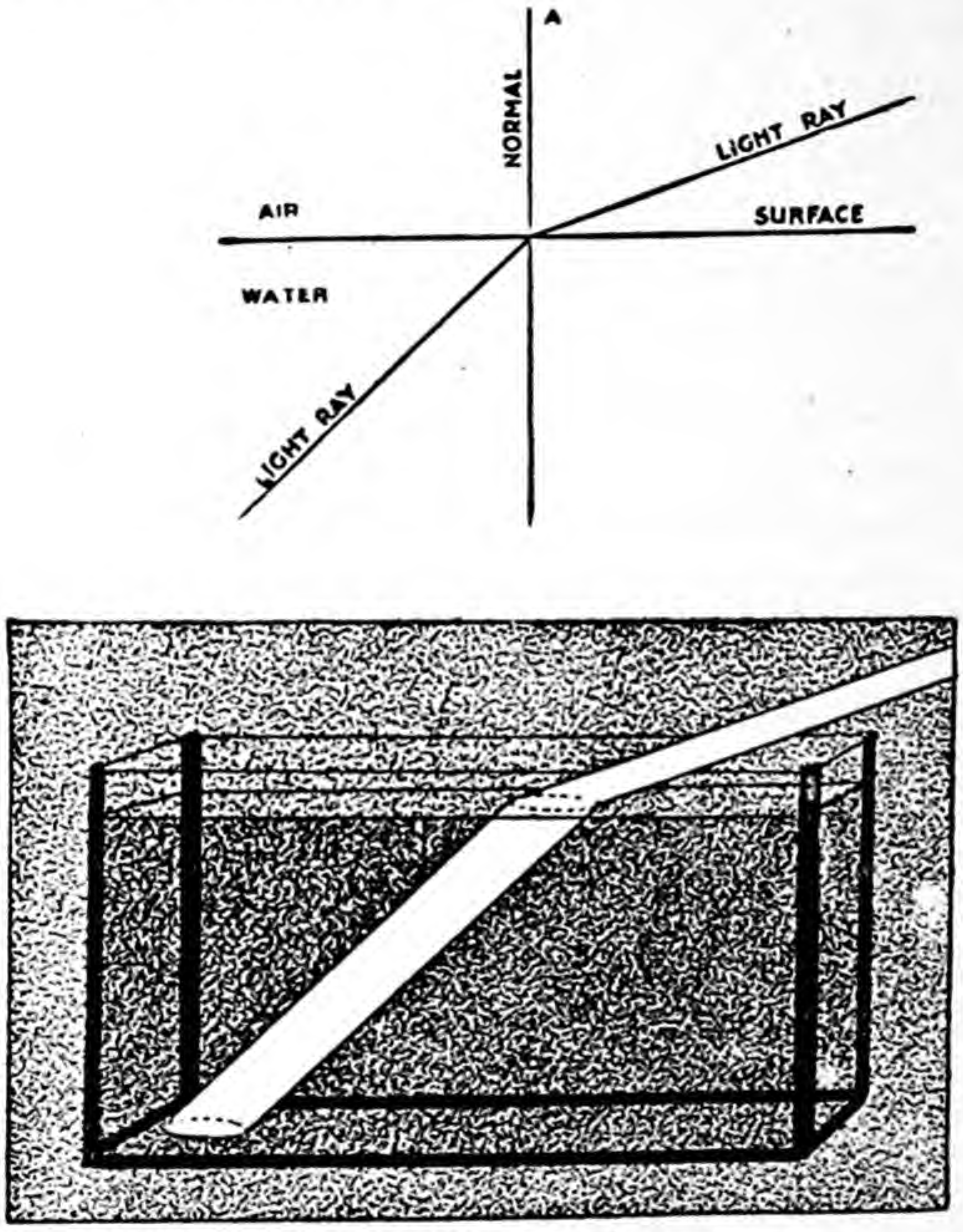


Fig. 85.—*Bending of light where it passes from air to water. Above, a diagram of the bending: below, how the bending can be shown by experiment.*

Only if the light is itself at right angles to the surface does it go straight through without being bent, as we should expect, for it cannot get any closer to the normal if it is already travelling along it.

The amount that a ray of light is bent depends upon the angle at which it strikes the surface, and upon the

substance. If it strikes at one particular angle the ray is bent more on passing into glass than on passing into water, and different kinds of glass bend it by different amounts.

This bending of light, which is called *refraction*, produces some strange effects. A stick put into clear water appears sharply bent at the surface, as shown in Fig. 86. The reason is that rays from the bottom of the stick S, for instance, are bent as shown in the diagram. The parts in

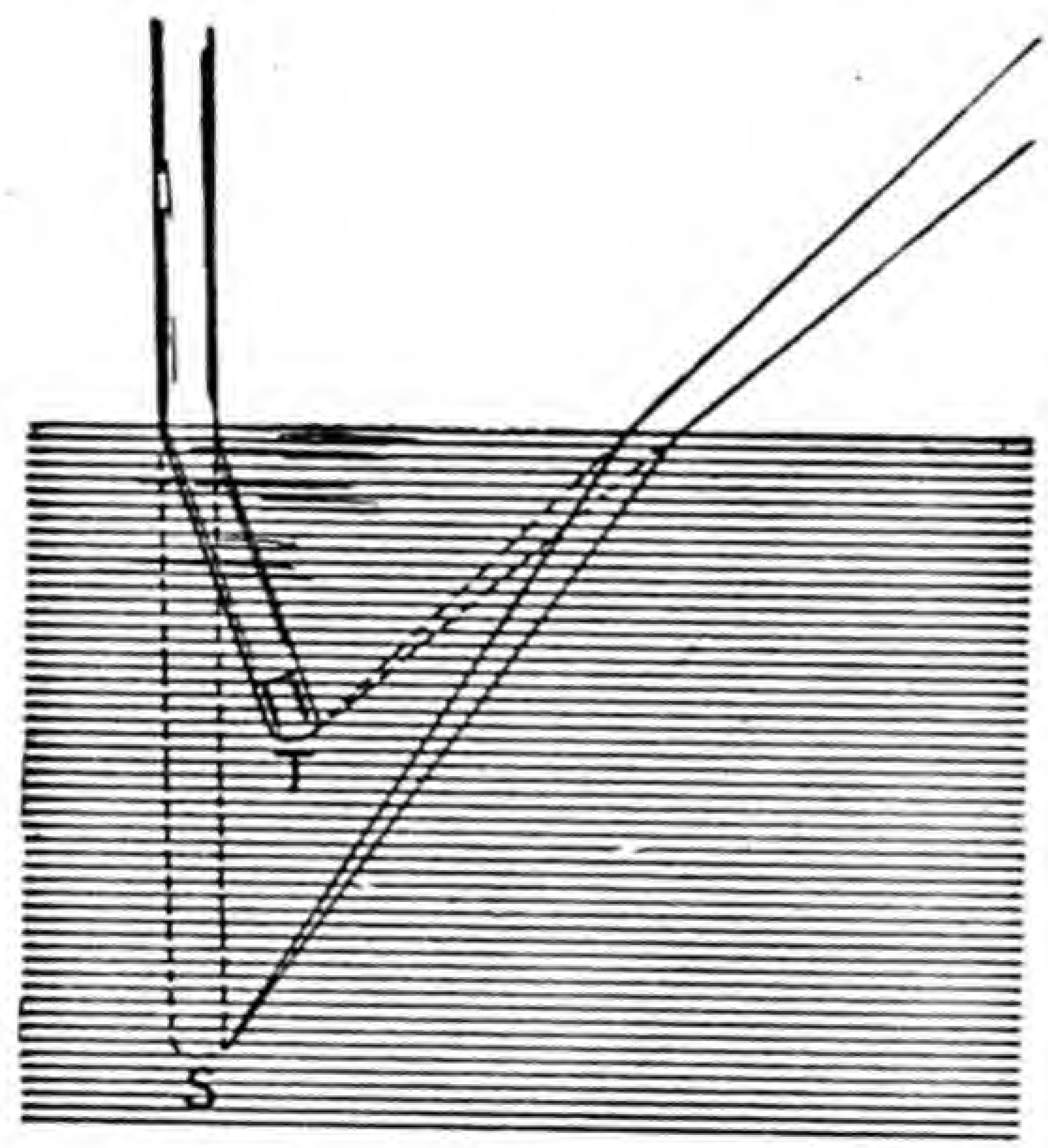


FIG. 86.—*Why a stick immersed in water appears bent at the surface.*

air travel exactly as if they had come *straight* from the point T. Now the eye does not follow rays back: it can only tell how they are travelling when they enter it, and judges where they have come from by supposing that they have travelled in straight lines from the beginning. In the same way a man who happens to be struck unexpectedly by a ball, judges that it has come from the direction in which it was travelling when it struck him: actually it may have come from some other direction, even the

opposite direction, and have bounced off a wall, or been turned aside from a tree, before reaching him.

The rays, then, enter the eye *exactly* as if they had come from T. They would also enter a camera as if they had come from T, and a photograph would show just what the eye sees, namely the point of the stick at T. In the same way a stream always looks shallower than it is, as can easily be seen from Fig. 87. The tin can on the bottom appears raised to the position shown.

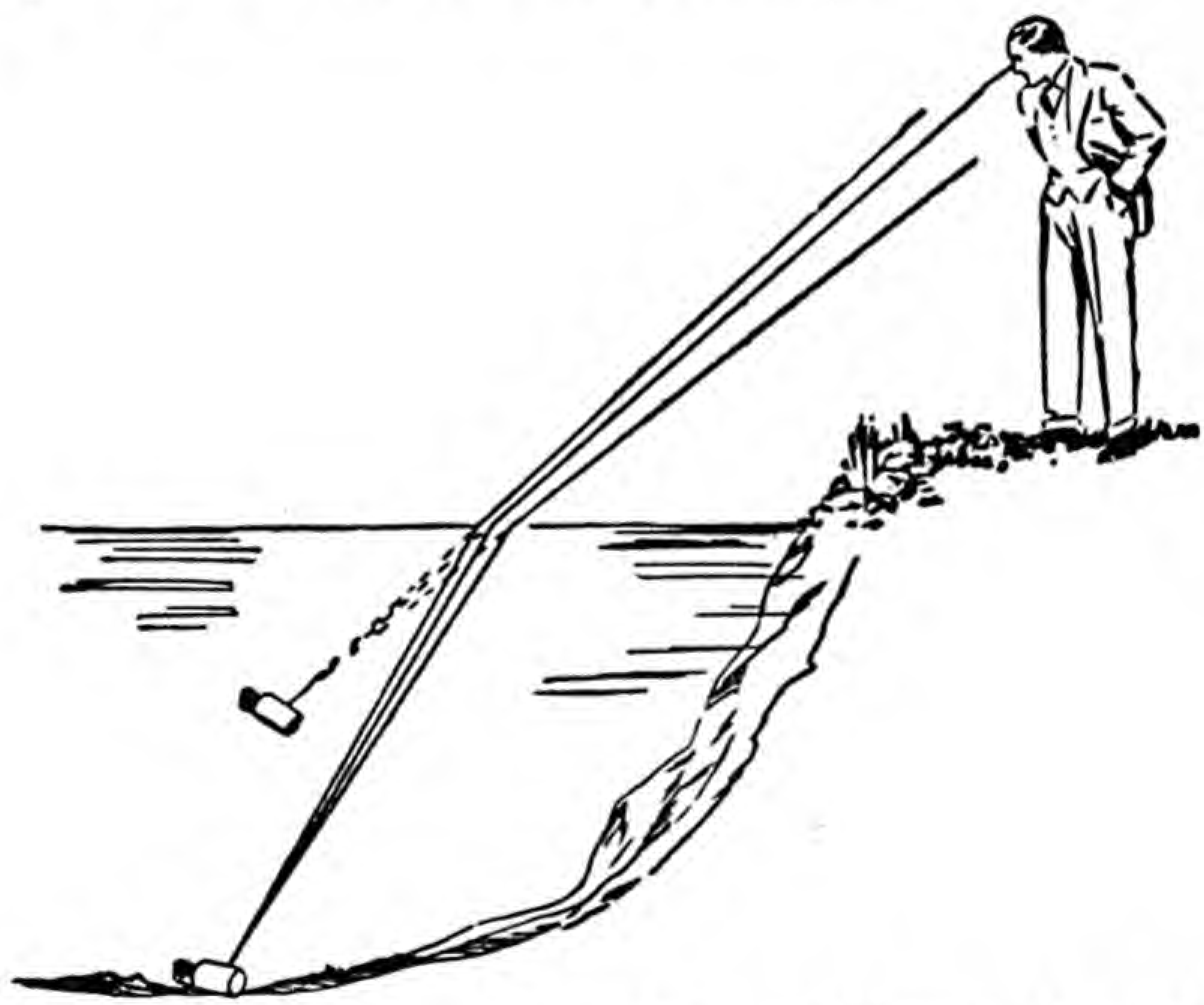


FIG. 87.—*Why a stream looks shallower than it is.*

A very pretty experiment is to put a penny at the bottom of an empty bowl, and to place the eye so that the edge of the bowl just prevents us seeing it, as shown in Fig. 88. If the eye is kept fixed, and water is poured into the bowl, the penny comes into view, for the rays from it are bent at the surface, and travel as shown in the picture. The bottom of the bowl appears lifted up, just as does the end of the stick in Fig. 86.

Now let us turn back to the question of the lens. A convex lens is a piece of glass with bulging surfaces, as shown in Fig. 89*a*. Think of a section through the

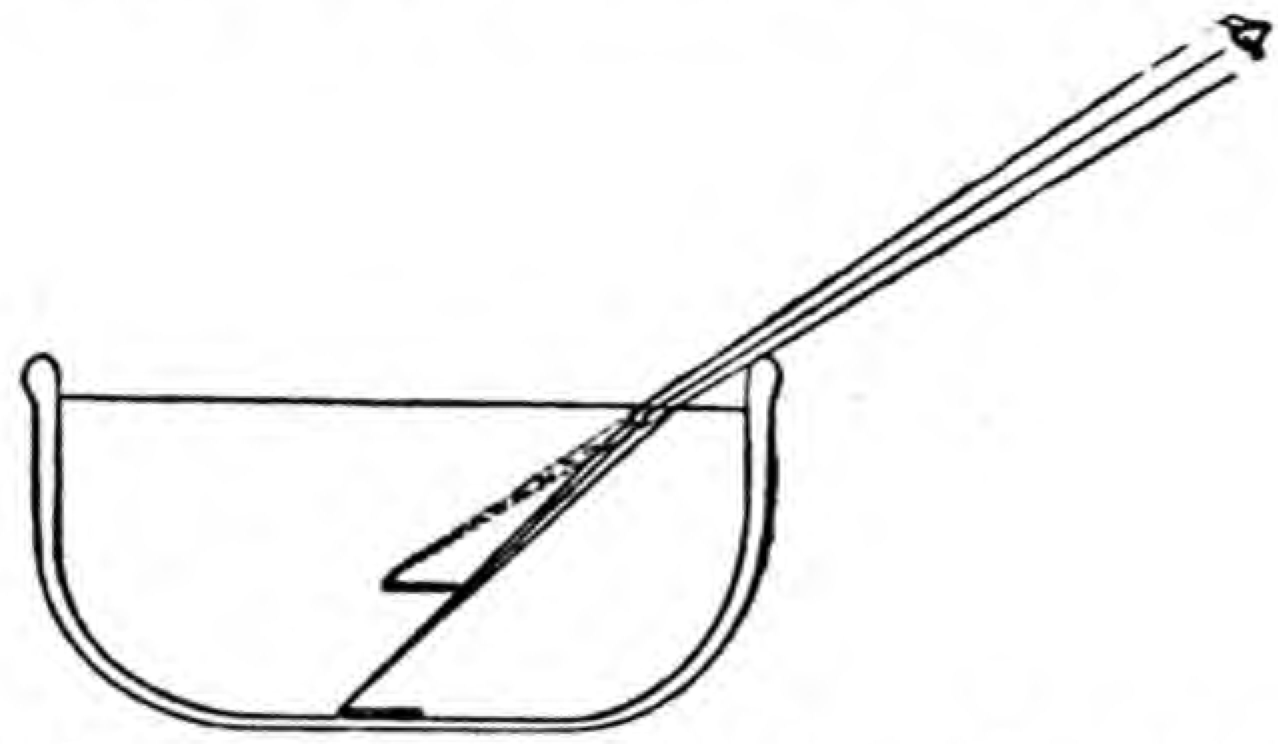


FIG. 88.—*With the eye in the position shown the coin cannot be seen when the basin is empty, but comes into view when water is poured in.*

middle of it, as shown in Fig. 90. A ray PB, which strikes the glass at B, is bent towards the normal, and travels in the glass along BC. When it leaves the glass

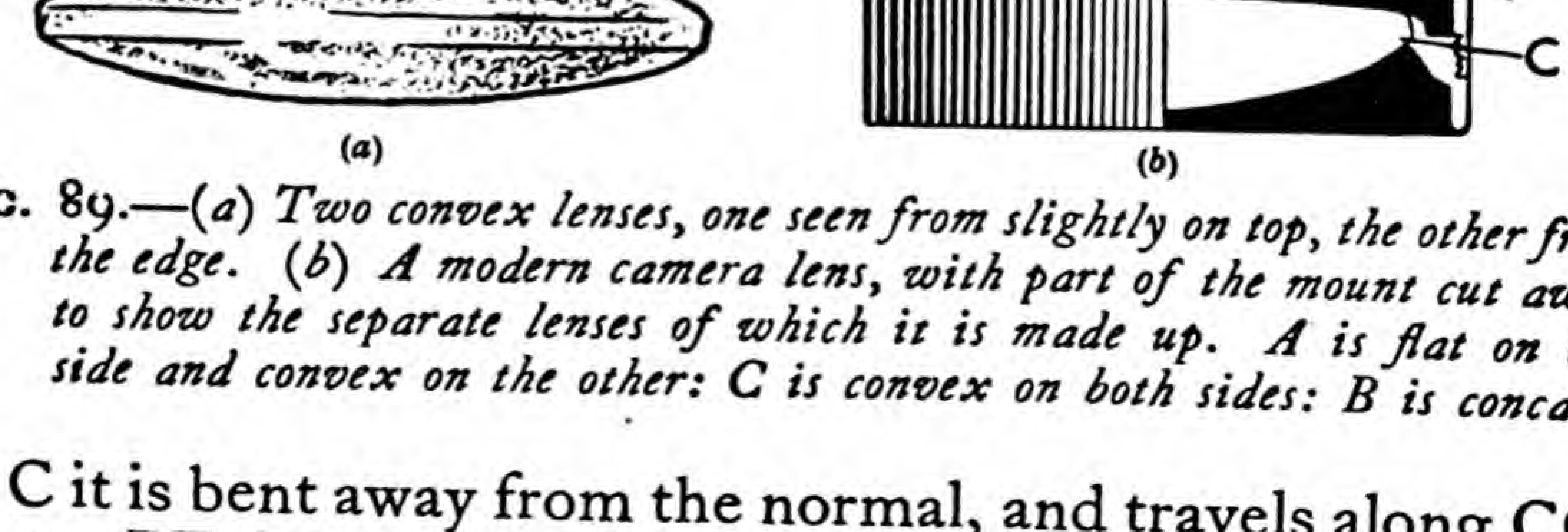


FIG. 89.—(*a*) *Two convex lenses, one seen from slightly on top, the other from the edge.* (*b*) *A modern camera lens, with part of the mount cut away to show the separate lenses of which it is made up. A is flat on one side and convex on the other: C is convex on both sides: B is concave.*

at C it is bent away from the normal, and travels along CQ. A ray PF from the same point P, which strikes the glass at a smaller angle with the normal at F is less bent, and

travels along FG, and so to Q. A ray which strikes the glass at right angles, at the middle, travels through without bending. The surfaces of a lens are parts of

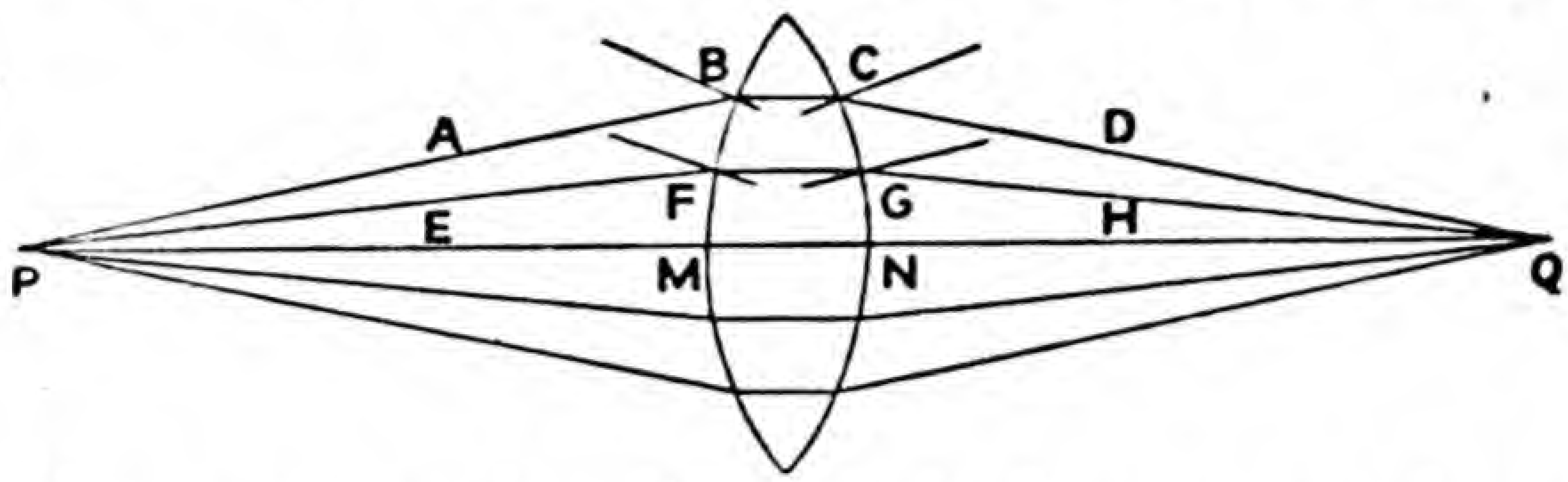


FIG. 90.—*How a convex lens brings light from a point P together again at a point Q.*

spheres, and it can be shown that the result is that all the rays from P pass close to one point Q on the other side, or, as we say, they come to a focus at Q. Actually, with a single lens, although they all pass *near* the point Q, it is not possible to make them pass *exactly* through it: with lenses like camera lenses, made up of several separate pieces, as shown in Fig. 89*b*, they can be made to come to a sharper focus. This is one of the reasons that good lenses have to be made up of different single lenses.

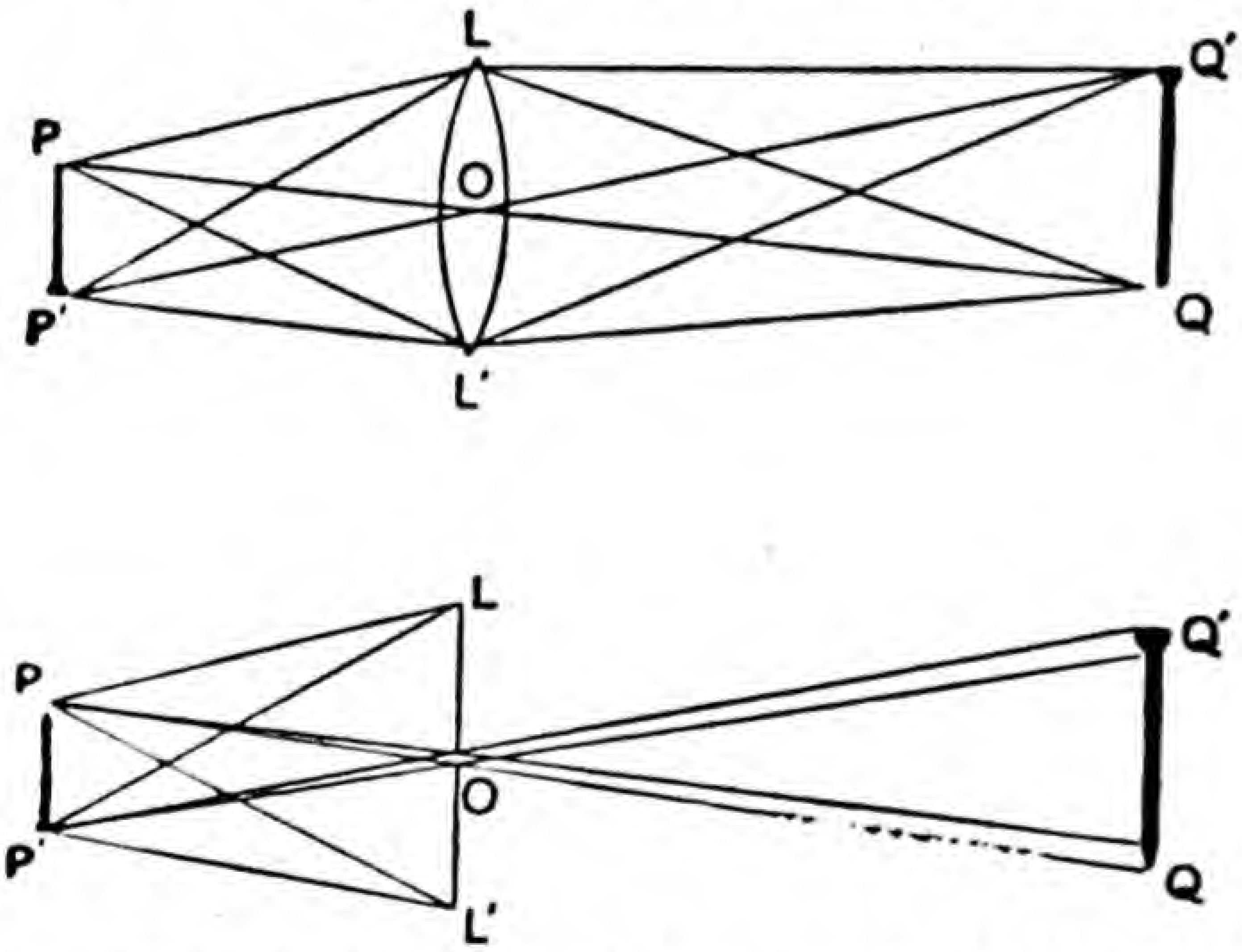


FIG. 91.—(*a*) *How the rays travel through a convex lens, and form an image.* (*b*) *An image formed on a screen at QQ′ by a pinhole in the same position as the lens.*

How, then, does a lens form a picture? Consider the nail on the left of Fig. 91. All the rays from the sharp end P which fall on the lens come together at the point Q, on the

line from P through the centre O of the lens. All the rays from a point P′ on the head of the nail come together at Q′, on the line through P′ and O, and similarly rays from every other point of the nail come together at points between Q and Q′. A sharp picture, or image, of the nail is found, then, at QQ′. How does this compare with the image formed by a small round hole? Firstly, with the hole, instead of a point Q we have a small round patch, and so for all the other points, so that the image is not so sharp. But there is a much more important difference than this. All the light from P that falls on LL′ comes to Q′ with the lens, but with the hole only the very small amount that can get through the hole comes to Q′. The image formed by the lens, then, is very much brighter than that which is formed by the hole. In fact if the lens is one inch across, and the hole is one-fiftieth of an inch across (which is about the size of an ordinary pinhole), 2,500 times as much light comes to any particular point, for the lens is not only fifty times as big up and down, but also fifty times as big across, so that $50 \times 50 = 2{,}500$ times as much light gets through. Using a pinhole camera with a hole one-fiftieth of an inch in diameter, we should have to expose for about 40 minutes to get as bright a photograph as we can get in one second with a lens of one inch aperture. This is the great advantage of a lens: it gives a sharp *bright* image. The larger the aperture, or opening, of the lens, the brighter the image, other things being equal, but it often loses a little in sharpness with the big aperture, as it is difficult to make a lens with which the rays striking near the outside edge are turned so as to come exactly through the same focus as those striking it nearer the centre. If a sharp picture is required, and the exposure need not be very short, the

photographer usually stops down his lens; that is, by a device provided in the camera he prevents the light passing through the edge of the lens, and uses only the middle part.

The lenses we have been considering bulge on both sides or bulge on one side and are flat on the other, and so are thicker at the middle than at the edge. Lenses which are thinner at the middle than at the edge are also used, and are called concave. Such a lens is represented in section in Fig. 92. Concave lenses do not form an image on a screen, as can be seen by considering the path of the rays from P, as shown in Fig. 92, which is drawn on the rule of bending towards the normal on going from air to glass, and away from the normal on going from glass to air. The rays CD and GH which leave the lens do not travel so as to come together, but get further and further apart. They behave, however, *as if* they came from the point Q. We know, then, that if they enter an eye the person will judge that they *have* come from Q, which is nearer to the eye than P. A concave lens, then, makes an object appear nearer, and that is why short-sighted people, who cannot see objects that are distant, use spectacles with concave lenses. They bring the objects nearer. Concave lenses also have many uses in optical instruments. In opera glasses and field glasses the lens near the eye is a concave lens, the front lens being convex, and the so-called telephoto lenses, used for taking pictures of distant objects, are also a combination of a convex and a concave lens.

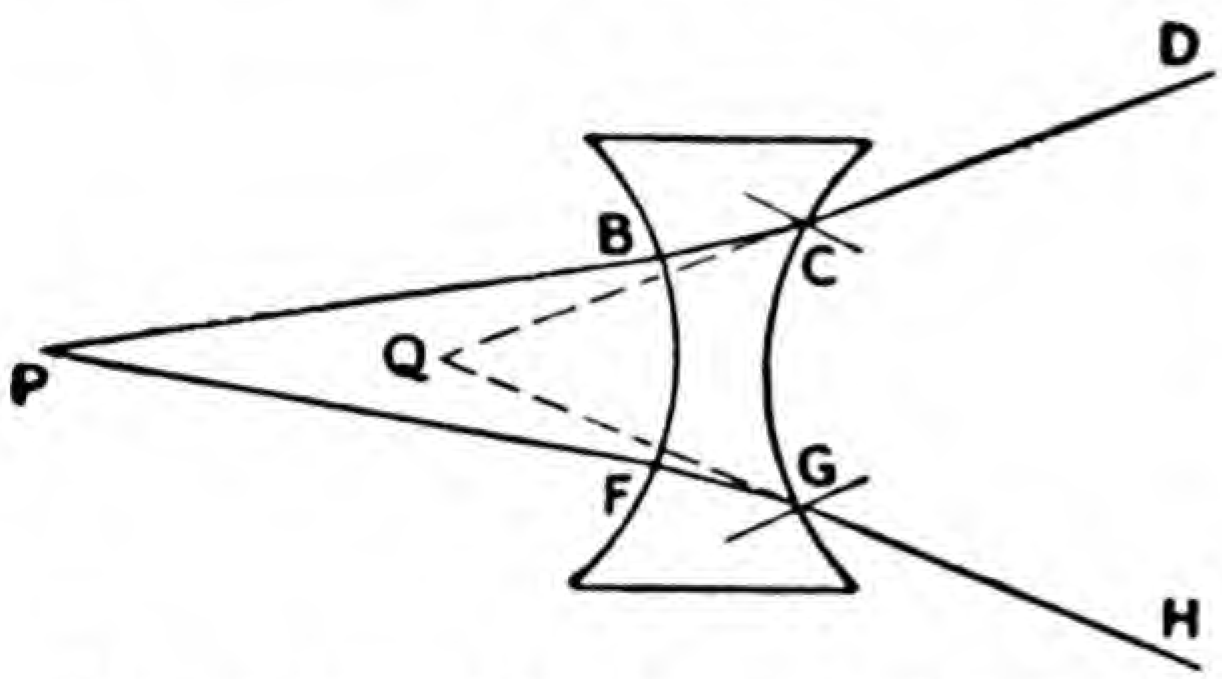


FIG. 92.—*The path of the rays through a concave lens.*

Reflection

When a beam of light falls on the surface of any opaque body, say a piece of white paper, or a piece of cloth, most of it is thrown back and travels out from the surface again. With any unpolished body the light of the beam, which comes from one direction, travels off again in all directions; it is scattered to all sides. On the other hand, with a mirror or with a well-polished surface, the beam travels off again in one particular direction, or is regularly reflected, to use the scientific words. If the coming ray is on one side of the normal to the surface, the reflected ray is on the other side of the normal, and both rays make an equal angle with the normal. We must also remember that coming ray (or incident ray, as it is called), and reflected ray and normal are all in one plane, which is the plane of the paper in Fig. 93. From whatever direction the incident ray comes, a flat sheet of card put through it and the normal at the point where it strikes the mirror will contain the reflected ray.

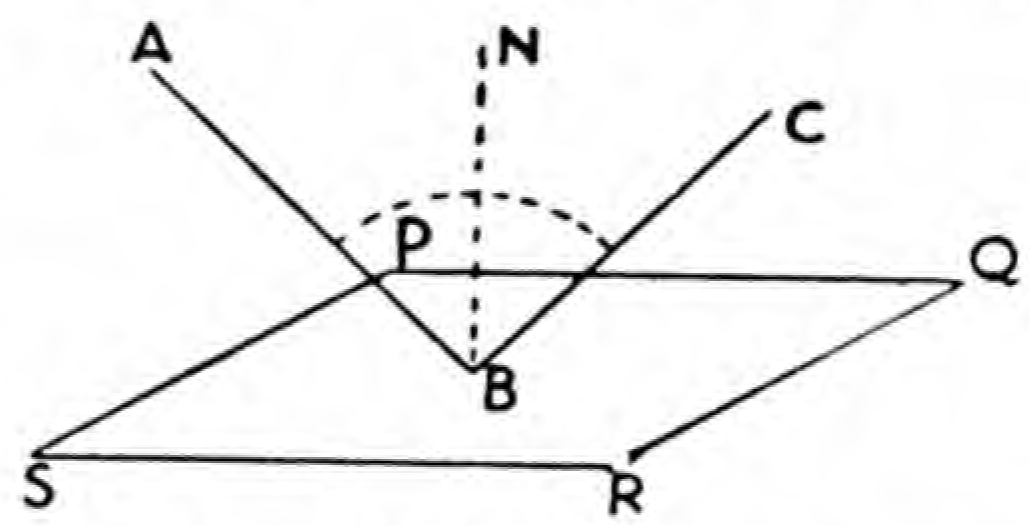


Fig. 93.—*The laws of reflection. You must imagine the reflecting surface PQRS to be at right angles to the paper on which the diagram is printed. If AB is the ray, and BC its path after reflection, and if BN is at right angles to the reflecting surface, then AB and BN and BC are all in the one plane, that of the paper, and the angle ABN equals the angle NBC.*

The reason that light is scattered at the surface of a sheet of white paper, say, is that the sheet is really not quite smooth, but rough, like blotting paper, only not so much so. Even the smoothest sheet has little irregularities. In consequence the light that falls on it strikes the sides of little microscopic hillocks and valleys, some on

one side and others on another, and therefore comes back in all directions. This is shown in Fig. 94, but it must be remembered that the rays coming off will not all be in the plane of the paper, but some will be thrown towards the reader, and some away from him as well. Light scattered in this way is sometimes said to be irregularly reflected, but it is better to keep the word "reflection" for regular reflection.

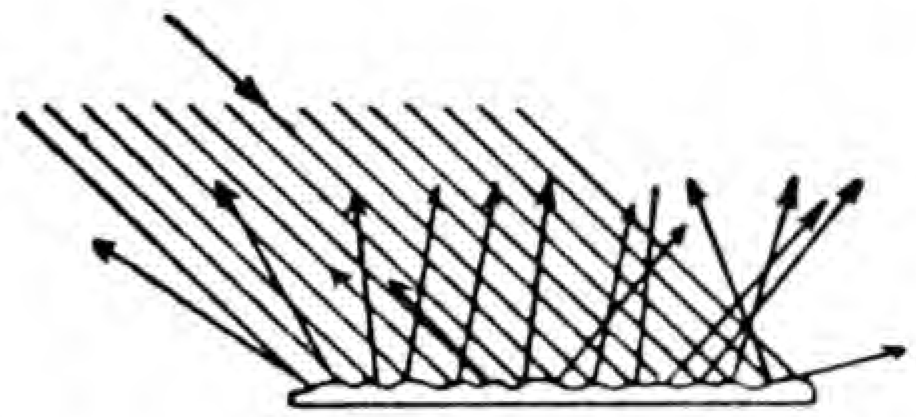


FIG. 94.—*How light is scattered at a surface which is not polished, such as blotting paper.*

People often forget how much light is thrown back by a white cloth or a white paper. The laying of a white tablecloth in place of one of dark cloth makes a big difference to the clearness with which objects in a room, especially in dark corners, can be seen—try it. If there is a bright light anywhere, such as good daylight or an electric lamp, a scrap of paper is often as good as a torch for throwing light into a dark corner. For instance, a piece of paper can be used to send light under a chest of drawers in searching for a stud: it must be held so as to catch the strong light. Or at night, with a car which has stopped, a piece of white paper held in the headlight will throw light on to the engine. Of course a piece of mirror is better, but firstly boys or men do not generally have a piece of mirror with them, especially out-of-doors, and, secondly, the mirror must be carefully arranged so as to throw the light exactly where it is wanted, while the exact position of the paper, which throws it to all sides, is not important.

From what we have said about the way in which things are seen, it would seem that the surface of the

mirror itself could not be seen except when the head is in a particular position, since light only comes off in one direction. However, we must remember that generally, when we see a mirror, light is falling on it in all directions, from objects all round it in the room, so that wherever we stand there is usually something so arranged that the light which it sends to the mirror is reflected into our eye. We see the reflection, and know that a mirror is there. It is quite easy to arrange a little experiment to illustrate what we have said about the difference between scattering and true reflection. Arrange a mirror horizontally against a dark curtain or a dark wall, opposite a window or open door through which the light comes, and place a piece of white paper on it. If you now look at the mirror, with the light coming from behind you, the paper will appear bright, and the frame of the mirror will be visible, but the mirror itself will appear quite black, although as much light is falling on it as on the white paper. To reach your eye by reflection, light would have to come from the opposite side of the mirror, but there is nothing there to give out light. The paper, however, can throw back the light coming from behind you.

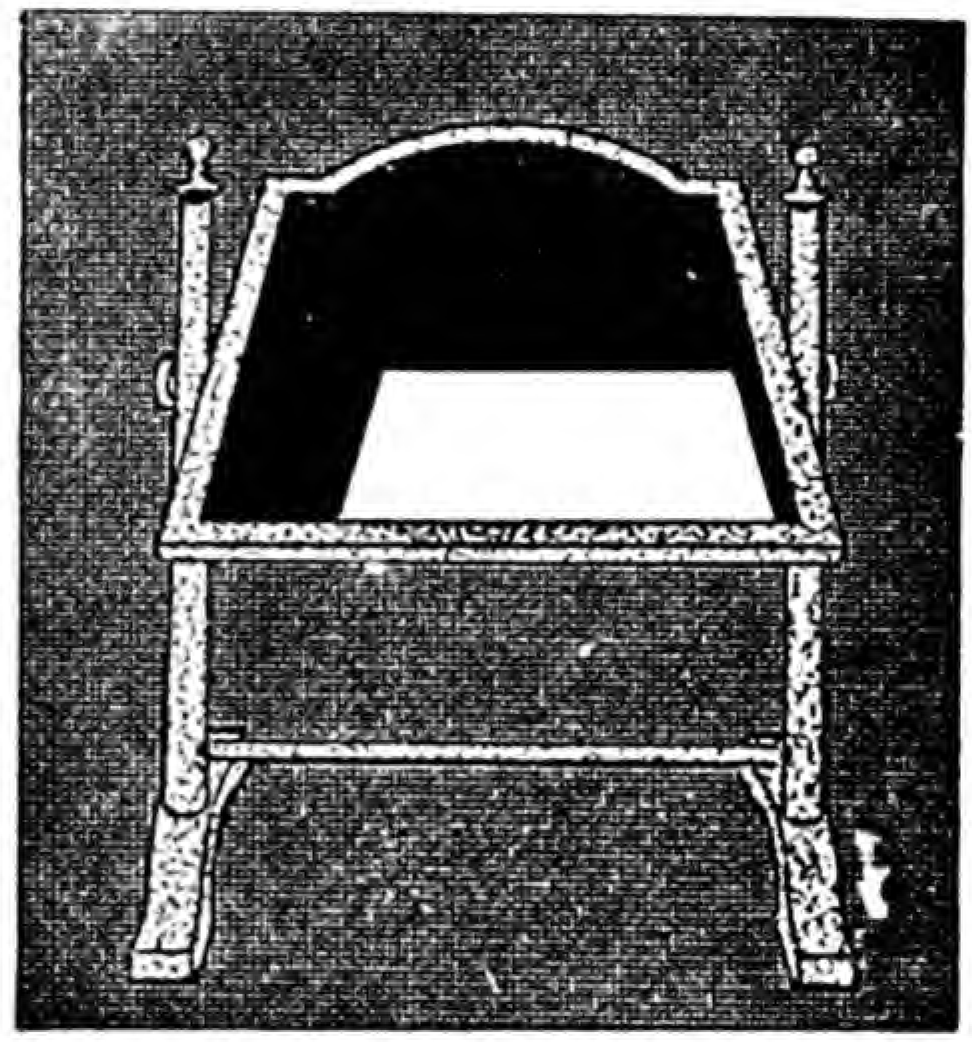


FIG. 95.—*When light falls on to the horizontal mirror from over your shoulder, the mirror looks black, because it throws back no light to the eye, but the paper laid on it looks white.*

What everybody knows about a flat mirror is that it gives a reflection, or image, as we say, of any object in front of it, but that it does not form an image on a screen

or a sheet of paper, like a lens does, no matter where the paper be held. To see how an image is formed by a mirror, suppose that MM is the line of the mirror, and P some point sending out light. One ray from P will be PRS (the angle PRN is equal, of course, to the angle SRN), and another will be PUV, the two rays moving apart as they leave the mirror, because the angle PUL is clearly bigger than PRN. The two rays, then, do not come together, but behave as if they were both coming from the point P′ *behind* the mirror. It is easy to show by geometry that P′ is as far behind the mirror as P is in front, and the PP′ is at right angles to MM.

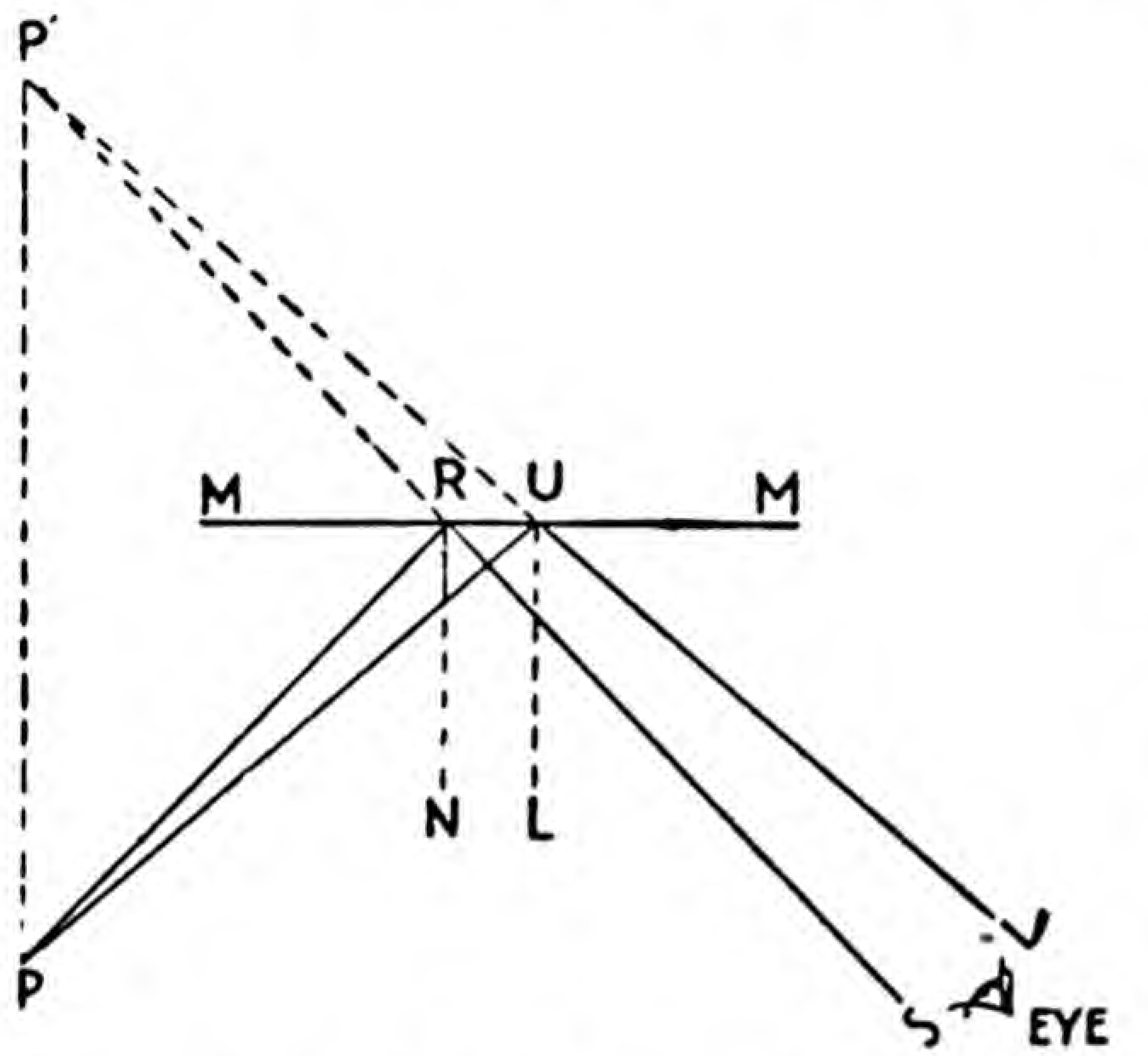


FIG. 96.—*How an image is formed by a mirror.*

Now we know that the eye judges the position of the source of the rays on the supposition that they have travelled straight all the way in the direction in which they enter the eye. To anyone looking at the mirror, from any position, therefore, there will appear a bright point, just like P, behind the mirror at P′, and, as this is true for any point P, a complete image of objects in front of the mirror will appear to be behind the mirror. Animals, in fact, think that there is something behind the mirror; a dog, seeing his image in the mirror, will try to get through the glass to the dog he believes is there.

It is easy to show that the image appears to be just as far behind the mirror as the object is in front. To do this we can make use of the fact that a sheet of ordinary glass reflects some light, although it lets most of the light pass through. We do not usually notice reflections in the windows of a room when we are inside, because they are faint, and the strong light coming through the window from outside overwhelms them, as a loud noise swamps a

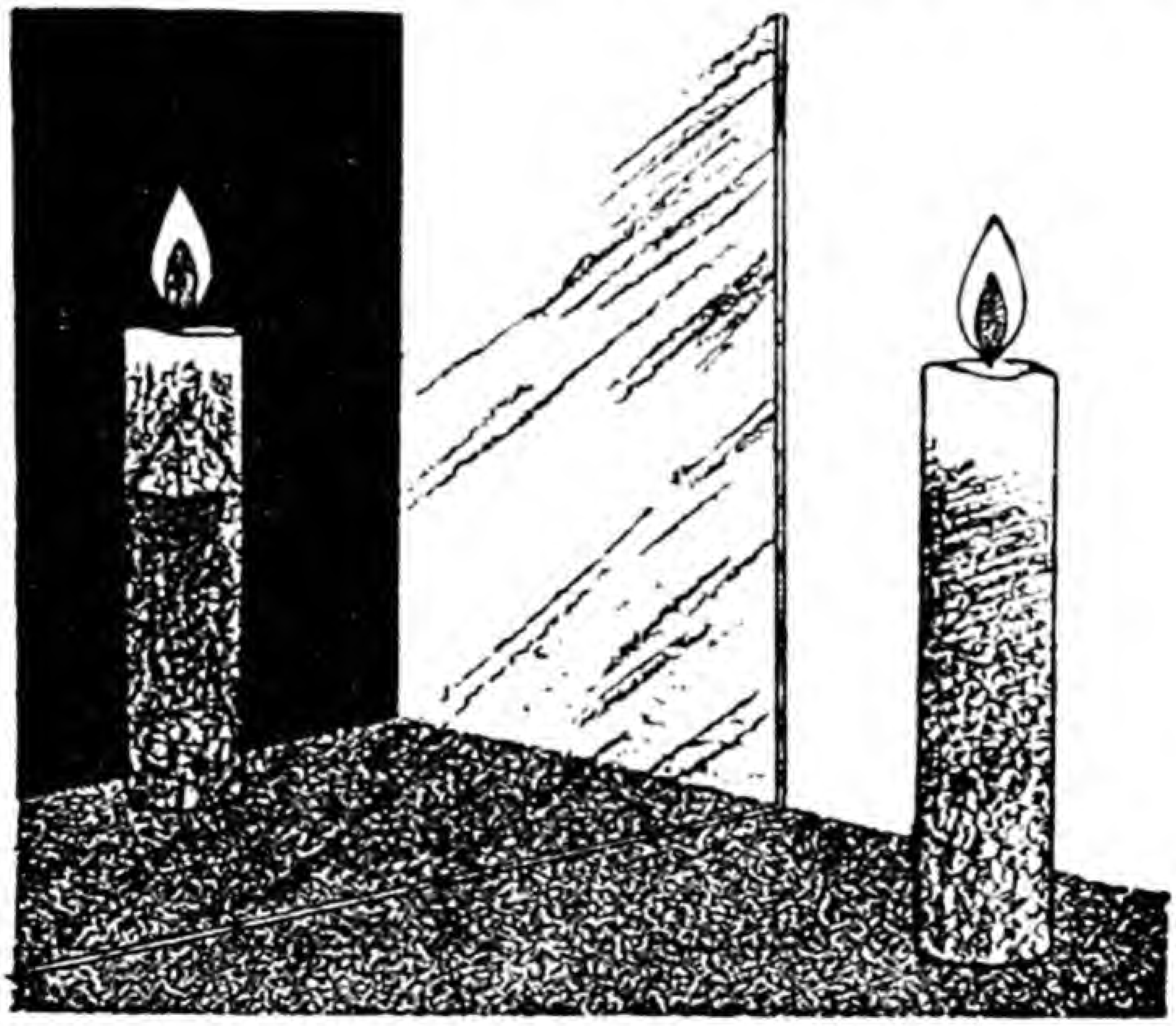


FIG. 97.—*To find the position of the image formed by a flat reflecting surface.*

faint sound, and prevents us hearing it. When it is dark outside, however, reflections in window glass are very plain. They can also easily be seen in shop windows on a bright day, when the people in the street are in strong light, and little light is coming from inside the shop windows, as every lady knows. We set up, then, a sheet of glass where there is no strong light behind it, and take two candles, one of which we put behind the glass, while the other we light and put in front of the glass. Looking into

the glass, we see both the real unlit candle behind it and a reflection of the lighted candle. We now move the lighted candle about, or get someone else to do it, until, *whatever the position of the eye*, its image exactly fits onto the real candle. When this happens the two must be in the same place, for although for one position of the eye the two might seem together if one was in front of the other, moving the head would then separate them. It will then be found that the lit candle and the unlit candle which gives the position of the image are placed just as P and P′ in Fig. 96 so that the line which joins them is at right angles to the reflecting sheet, and the unlit candle is as far behind it as the lit candle is in front of it.

If a boy stands behind the sheet of glass, and places his hand opposite the lit candle, and as far behind the glass as the candle is in front of it, he will seem to be holding a candle, and yet he can put his other hand through the place where it is. He has the ghost of a candle. A very good illusion used to be shown on the stage which depended on the same kind of reflection: as it was first shown by a man named Pepper it was called Pepper's Ghost. In front of the stage a plate of glass was arranged sloping forward at about 45°, with its edges hidden by curtains, so that the audience could not see them. In front of the bottom of the glass was a kind of well, lined with black cloth, and hidden from the audience by some kind of little wall, as shown in Fig. 98. Lamps

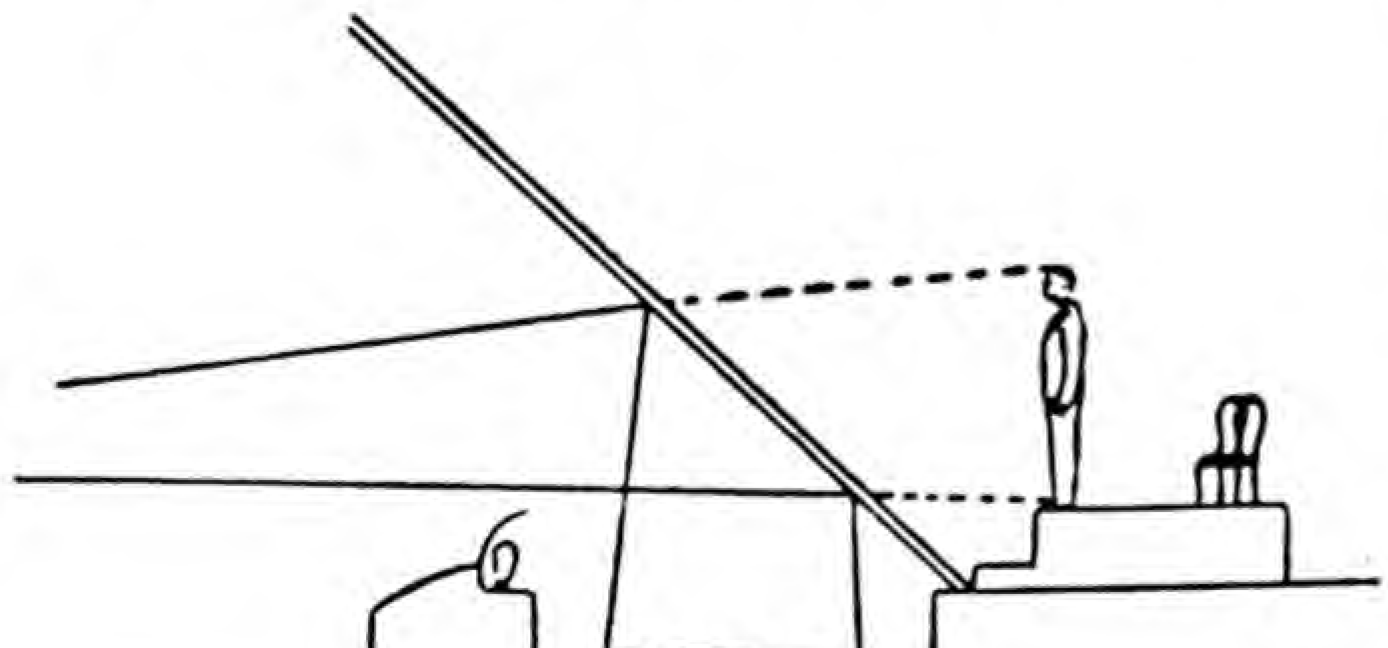


Fig. 98.—*Pepper's ghost.*

were arranged so that anyone in this box would be very brightly illuminated. If, then, an actor lay in this well, with his head towards the audience, his image would be seen upright, and as if behind the glass, so long as the light behind the glass was not too bright, as we have explained. By having suitable lights behind the glass, flesh and blood people walking about there could be made to show just about as plainly as the image of the actor in the well, so that both looked equally real, but the people could walk through the image, and put their hand through it. Of course, the actor in the well could move his arms, and make the image do the same. This effect can easily be arranged in a model theatre, so long as it is remembered that while a very bright light must be thrown on the figure, doll or what not, that makes the "ghost," the actual stage must not be too brightly lit. With a little practice a very striking "ghost" can be made.

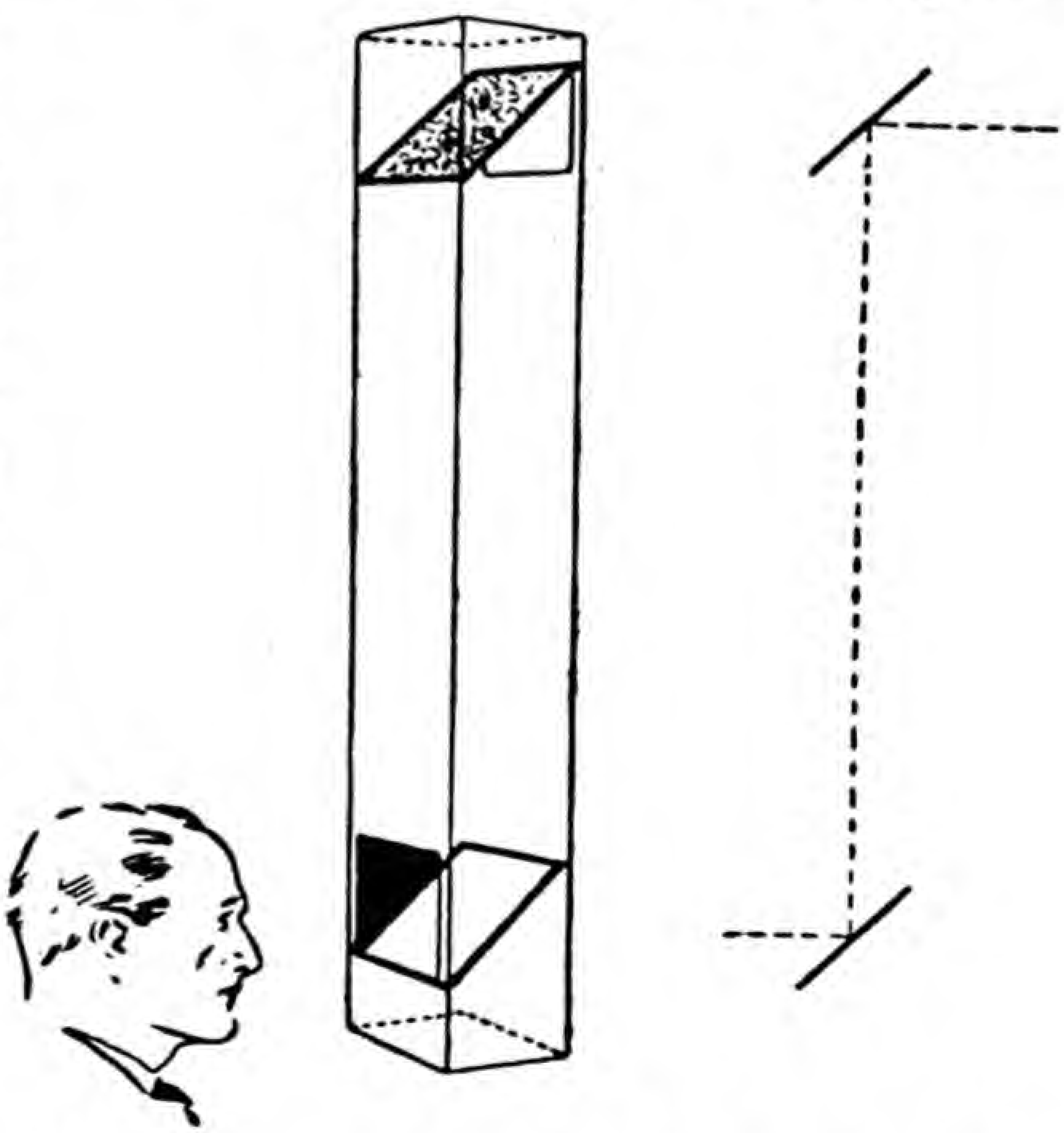


FIG. 99.—*A periscope. The path of the rays is shown on the right.*

A good example of the laws of mirror reflection is offered by the periscope, which is an instrument allowing us to see over an obstacle, such as a wall or the heads of people in a crowd. It consists of two mirrors, arranged parallel to one another, and at 45 degrees to the horizontal, as shown in the diagram.

They may be fixed in a box, one above the other, as shown in the picture, or, in the simplest form, merely fastened to a stick. Light from the scene in front falls on the upper mirror, is reflected to the lower one, and from it horizontally into the eye of the observer, who sees what he would see straight in front of him if his eye were at the position of the upper mirror. This kind of periscope was used in the trenches during the Great War, to save soldiers putting their heads above the parapet when they wanted to look out. Periscopes are also used on submarines, the upper mirror being carried at the top of a tube some 20 feet long, while the lower is in the boat. In order to see, only the upper mirror need be pushed above the surface of the sea. Actually, instead of mirrors, reflecting prisms are used, as described on page 145, and lenses are also arranged in the tube in such a way as to enable the sailor to see a wider view than he could do with mirrors only. The principle of the two reflections is, however, just the same as in the simple periscope of Fig. 99.

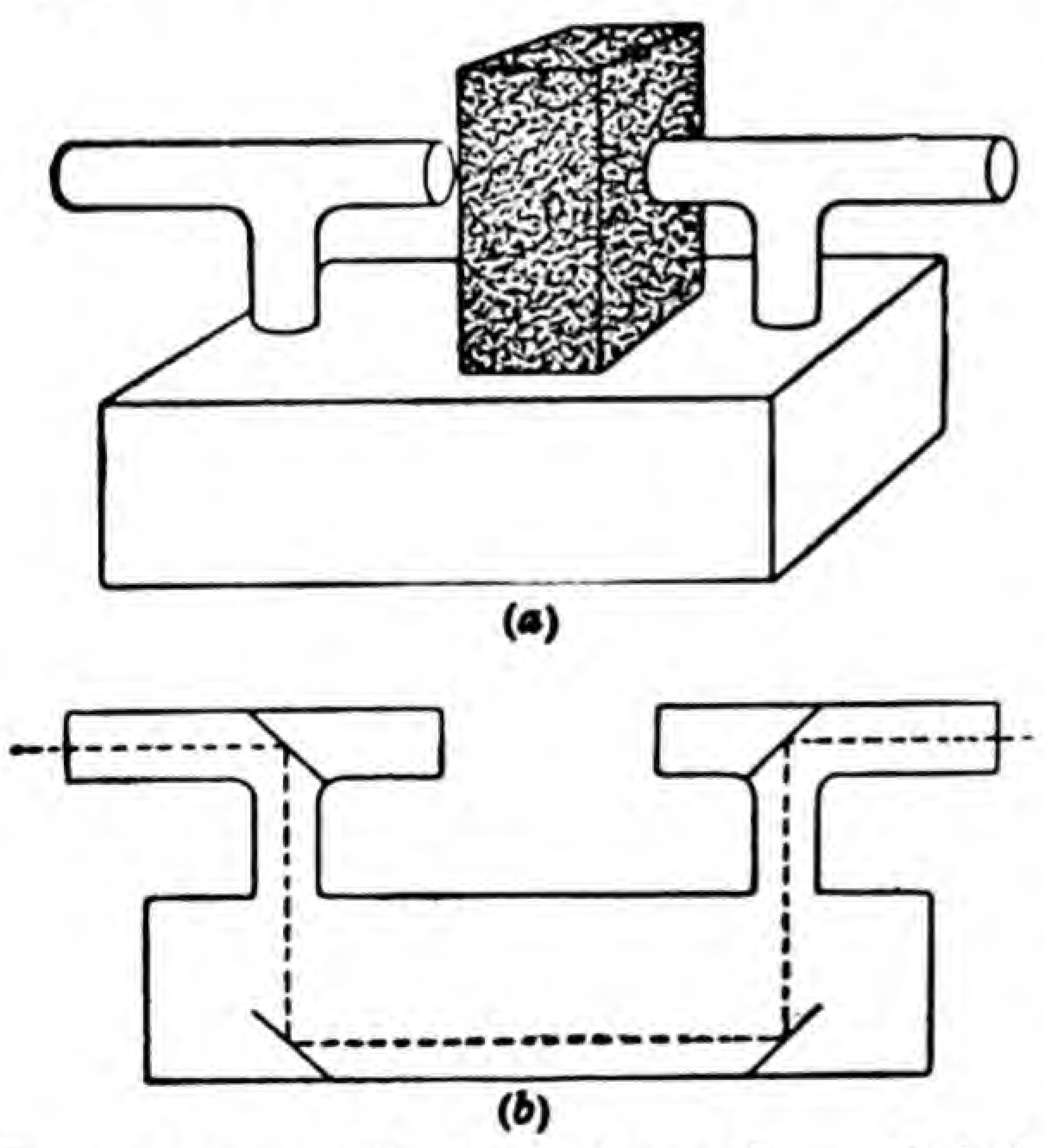


FIG. 100.—*Seeing through a brick. The path of the rays is shown below.*

An amusing trick, called "seeing through a brick," is another good example of the use of mirrors. Two little tubes, which appear to have ordinary lenses in them, like telescopes, are arranged in line with a gap between them, as shown in Fig. 100*a*.

Anyone who looks through sees the wall or the scene opposite him, just as if he was looking through a hole. If a brick is now put between the two "telescopes" he still sees the same scene, so that, if he does not know the trick, he thinks that he is seeing right through the brick. Fig. 100*b* shows what really happens. The pieces of glass at each end of the telescopes are not lenses, but ordinary flat glasses, and have nothing to do with the trick. The supports of the telescope are hollow, and allow the light to be reflected, by four mirrors, placed as shown, first down, then underneath the brick, up again and out into the eye on the other side. What the observer sees is just the same as if he were looking straight through. Putting in the brick makes, of course, no difference. It is quite easy to make up this trick for yourself. If you can get hold of four reflecting prisms (see p. 145), instead of four mirrors, so much the better.

An ordinary mirror, such as is used on a dressing table, is a piece of glass covered on the back with a thin coating of silver, which is then varnished and covered with a thick coat of special red paint, to prevent it tarnishing. It is this red paint that you see if you take a mirror out of its frame. The silver reflects very well, and the glass in front protects it from damage. We know, however, that glass itself reflects, and if we look slantingly into a piece of mirror we shall see that there are two images of everything: one strong one formed by reflection at the silver, and a much fainter one formed by reflection at the glass in front. In strong light several more fainter images can be seen, caused by the light being repeatedly reflected between the silver and the front of the glass, and some of it coming out after each reflection, as shown in Fig. 101*a*. To see these images, take a thick piece of mirror, and

hold it near the eye so that the light from a candle, say, strikes it so as to make an angle of 20° or so with the surface. A whole series of images of the candle will be seen, getting fainter and fainter as shown in Fig. 101*b*. If a brighter object is taken, say an electric lamp, even more images can be seen.

This second image, and the other fainter images, do not worry us in an ordinary mirror, but in scientific instruments it is very important only to have one clear image.

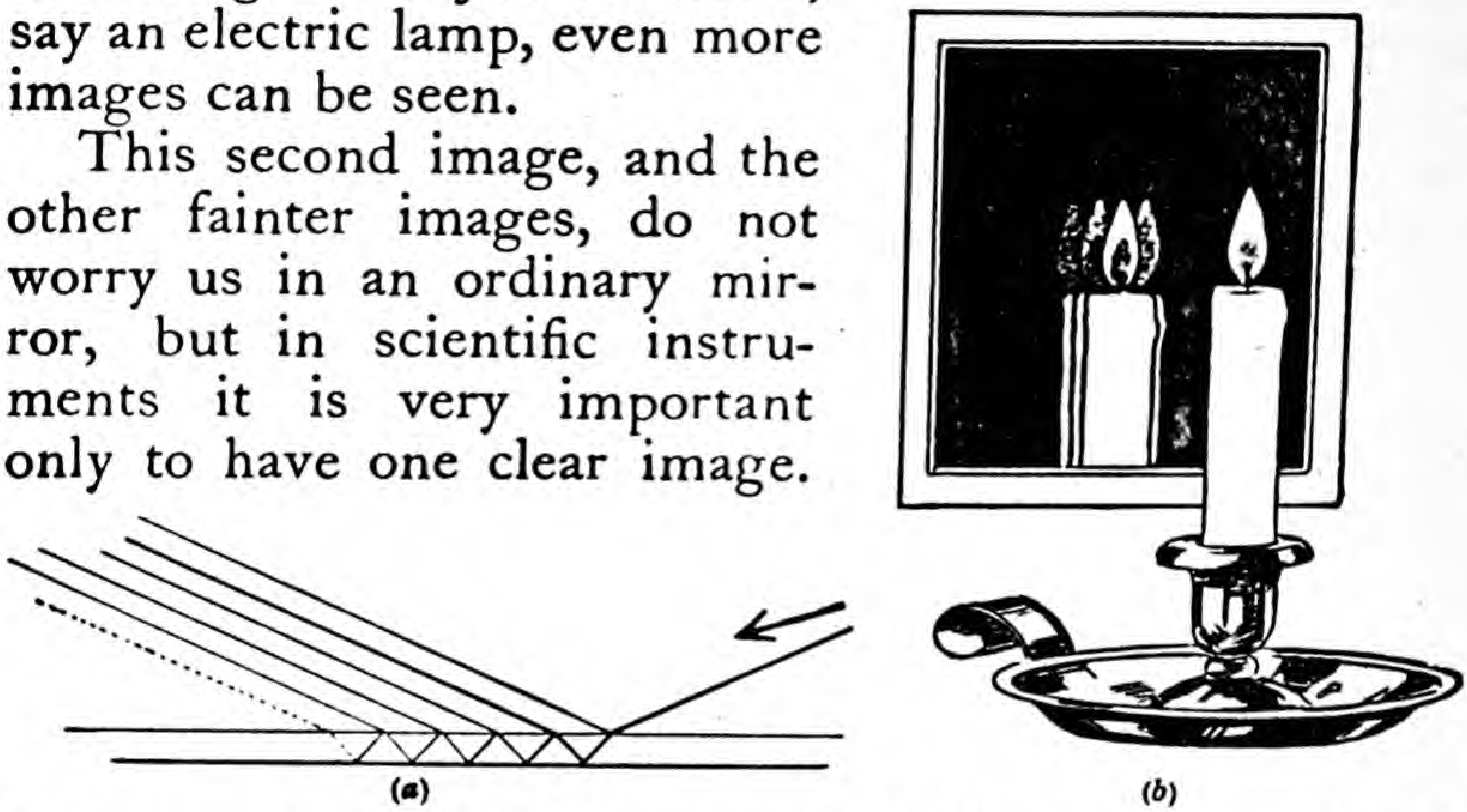


FIG. 101.—*Many images in a mirror.* (*a*) *How the many images are formed;* (*b*) *what is seen with a candle.*

The mirrors used by astronomers are, therefore, always silvered on the front of the glass. The silver, instead of being protected by the glass, as in an ordinary mirror, is then exposed to the air, which is troublesome. It must not on any account be fingered, and in any case it slowly tarnishes. Astronomical mirrors, therefore, have to be resilvered from time to time, say once or twice a year. The mirror of the great reflecting telescope—the largest in the world—at the Mount Wilson Observatory in California, which is 100 inches across, can, whenever required, be lowered by machinery into a special silvering room, where it is carefully cleaned and immersed in the

silvering bath, which consists of a solution of chemicals containing silver, from which the silver settles on the glass.

There is another way of getting reflection at one surface only, which avoids the easily injured silvering on the front. To understand it we must go back to the bending of light in passing from glass to air. Suppose that a ray AO, making an angle of 80° with the normal in air, falls on the glass; it will be bent towards the normal and actually will make an angle of 38° in the glass, as shown by OB in Fig. 102.[1] If it makes as big an angle as possible in air, that is just less than 90° (let us say 89·9°), it will be bent slightly less towards the normal, the angle being 38·8°, as shown by CO and OD. If we now think of the ray reversed, that is, travelling in the glass towards the air, this means that a ray which in the glass makes an angle of 38·8° with the normal comes out travelling practically along the surface of the glass. Suppose the ray makes a bigger angle than 38·8°, say 45°, in the glass, what then? The ray clearly cannot get out. Actually it is reflected at the surface of the glass back again into the glass, just as at a mirror, the path of the ray being EO, OF. This is called total internal reflection.

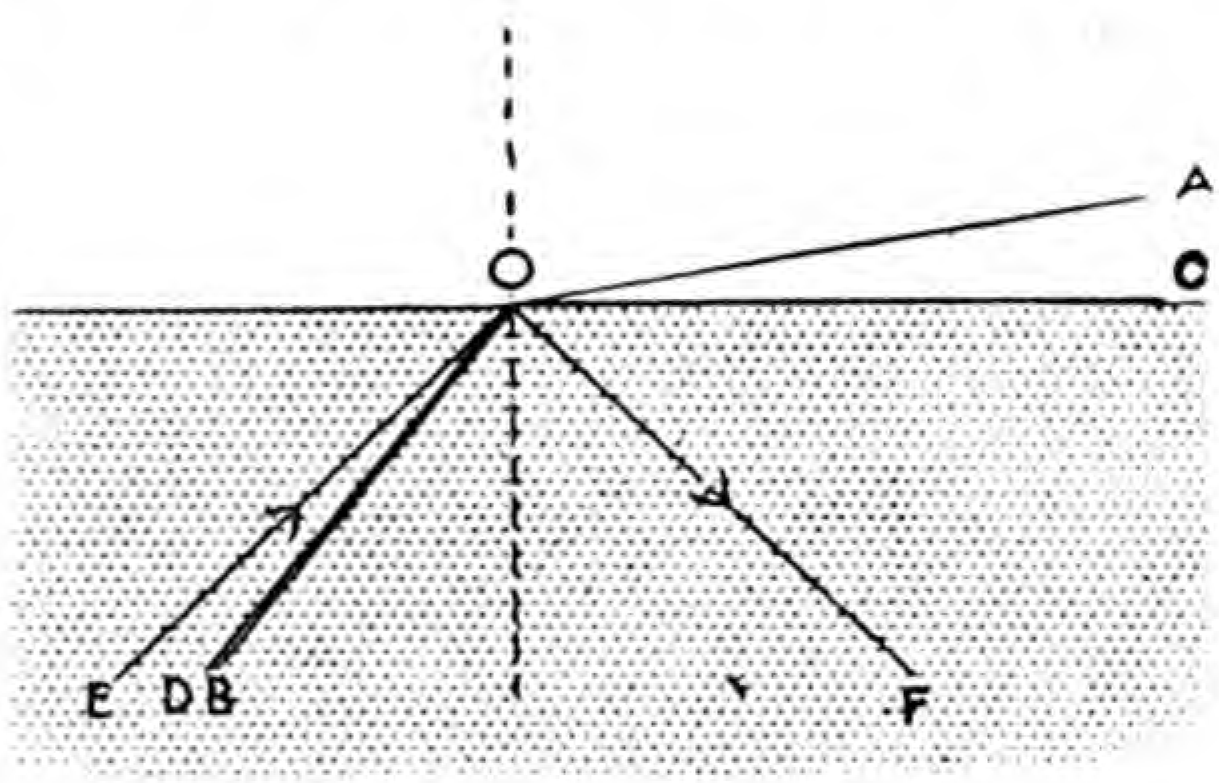


FIG. 102.—*Diagram to illustrate total internal reflection. The ray DO in the glass is bent, where it leaves the glass, so that it travels along OC, grazing the glass surface; the ray EO cannot leave the glass, but is reflected back along OF.*

[1] The exact angle depends, of course, on the kind of glass, but it will not be very different from this with any ordinary glass.

It is very easy to see this kind of reflection in water. If a clean glass of water, with a spoon in it, is held up high and looked at from underneath, the lower part of the spoon, which is in the water, will be seen reflected in the surface, and the upper part of the spoon will be invisible. Or if a piece of mirror is placed in a trough or bath of water, and light from an electric torch shone straight down on it, then when the mirror is lying nearly flat the light will come out of the water, but when the mirror is slowly tilted by pushing a piece of metal, say, under one side, an angle will suddenly be reached when the beam will not come out of the water at all, but will be reflected at the surface, and form a patch of light on the bottom of the tank, as shown in Fig. 104.

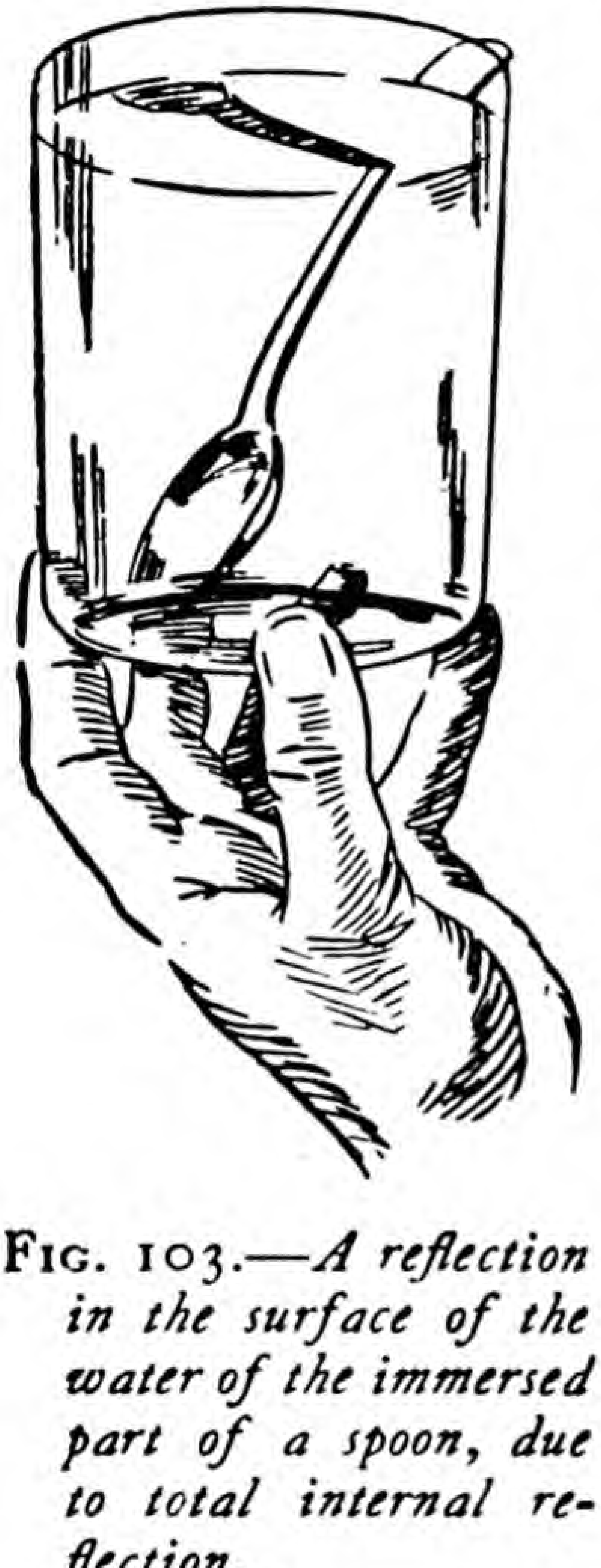


FIG. 103.—*A reflection in the surface of the water of the immersed part of a spoon, due to total internal reflection.*

FIG. 104.—*Total internal reflection in a tank of water.*

It is also interesting to think of what a fish in water sees. A fish-eye view is very peculiar. A ray just grazing the surface of the water makes an angle of about 49° with the normal in the water, for water does not bend light as much as glass. No ray from above the water can, there-

fore, come to the fish's eye making a bigger angle than this with the normal, from whatever side it comes, and thus everything will for him be crowded together so as to be seen through a circle of radius OA and centre O, no matter what the shape of his pond, for clearly every point on such a circle will make the same angle OEA. Thus the man's feet will be seen by the fish as lying in the direction EA. Professor R. W. Wood took a fish-eye

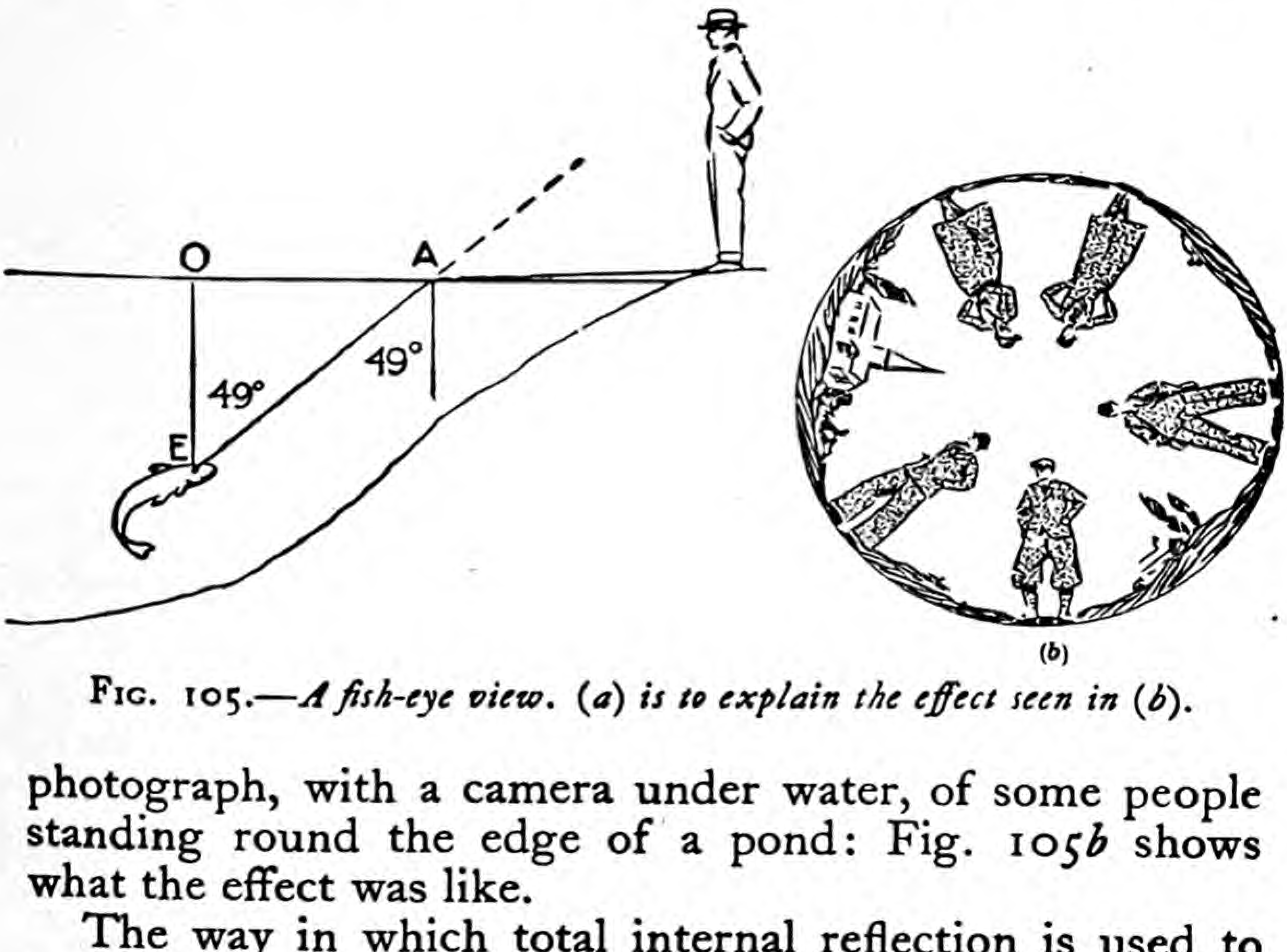


FIG. 105.—*A fish-eye view. (a) is to explain the effect seen in (b).*

photograph, with a camera under water, of some people standing round the edge of a pond: Fig. 105*b* shows what the effect was like.

The way in which total internal reflection is used to get a reflection at one surface only can now be understood. In Fig. 106*a*, ABC is the top view of the prism of glass shown in Fig. 106*b*: ABC is a right angle, and the other two angles are both 45°. A ray QR will pass through the surface AB without bending, as it falls on it at right

angles, and will meet the face AC, travelling in the glass, at 45°. We know that such a ray cannot escape, but will be reflected at the surface AC, and come out through the other face CB. Such a prism, so used, is called a total reflection prism, and is used in field glasses and many other instruments, and as the view-finders of cameras.

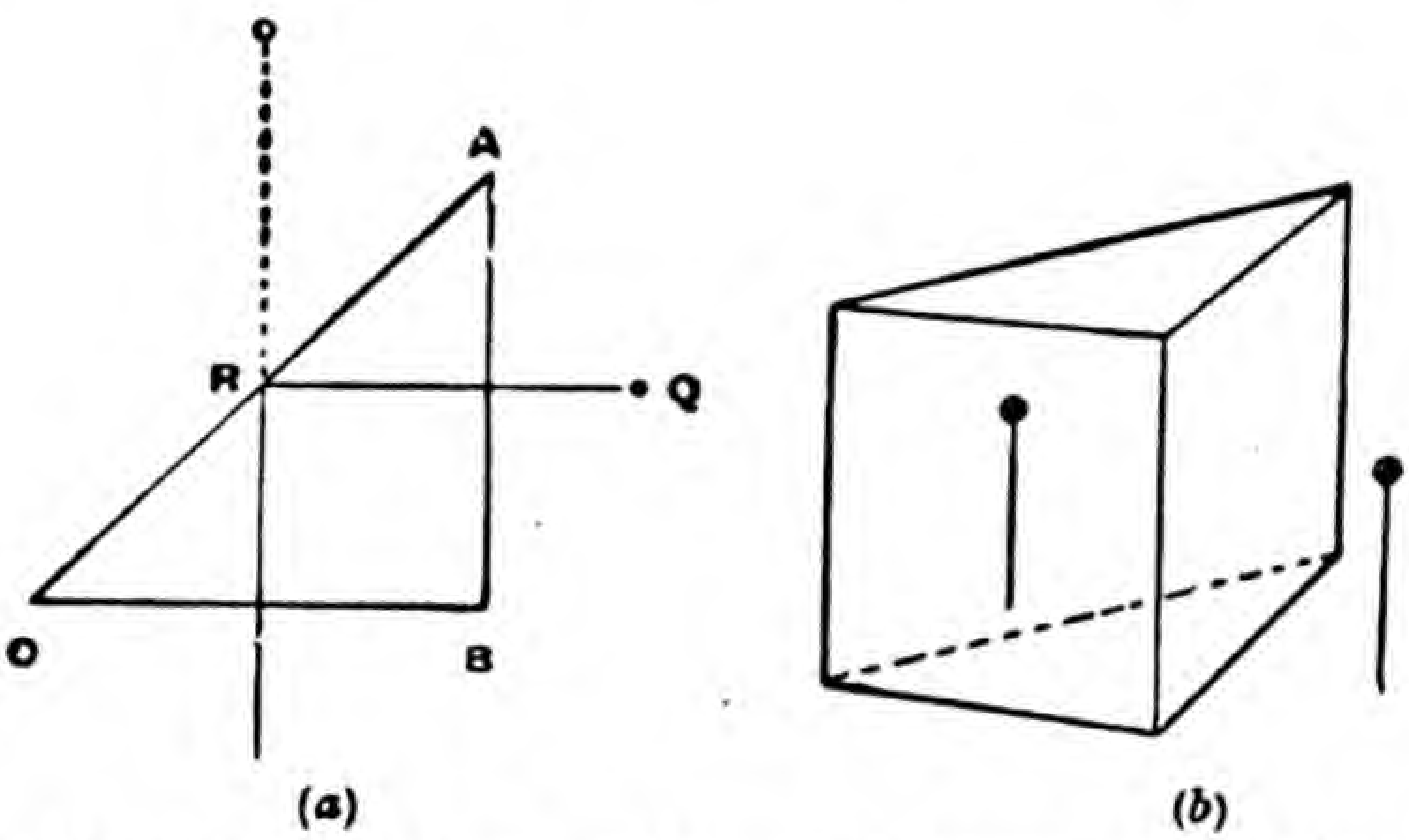


FIG. 106.—*Reflection with a right-angled prism. The path of the rays is shown in (a), the appearance of the pin and its reflection in (b).*

It makes a splendid reflector, for the reflection all takes place at the one surface AC. Two such prisms are used, for instance, in the periscopes of submarines, instead of the two mirrors shown in the simple diagram on p. 139.

COLOUR

Sir Isaac Newton (1642-1727), probably the greatest man of science the world has ever known, carried out some experiments with a prism which first showed the nature of colour, and they were so clear that we cannot do better than describe the most important of them.

He allowed a thin beam of sunlight to enter a dark room through a small hole in a shutter, and to fall on a

glass prism,[1] point downwards, as shown in Fig. 107. The beam came out of the prism and fell on a sheet of white paper. If there had been no prism the beam would have formed a small circle of white light on the paper, but instead of that a long band appeared, which in Newton's experiments happened to be about 10 inches long. The length depends, of course, on how far off the screen of paper is placed, and it also depends, to some extent, on the kind of glass from which the prism is made. This band was coloured, the top being violet and the colours then following in the order indigo, blue, green, yellow, orange to red at the other end. Such a band is called a spectrum, and the colours are called spectral colours. A colour like purple, which is a mixture of blue and red light, or a colour like brown is not a spectral colour. It is rare to find a really pure spectral colour in nature.

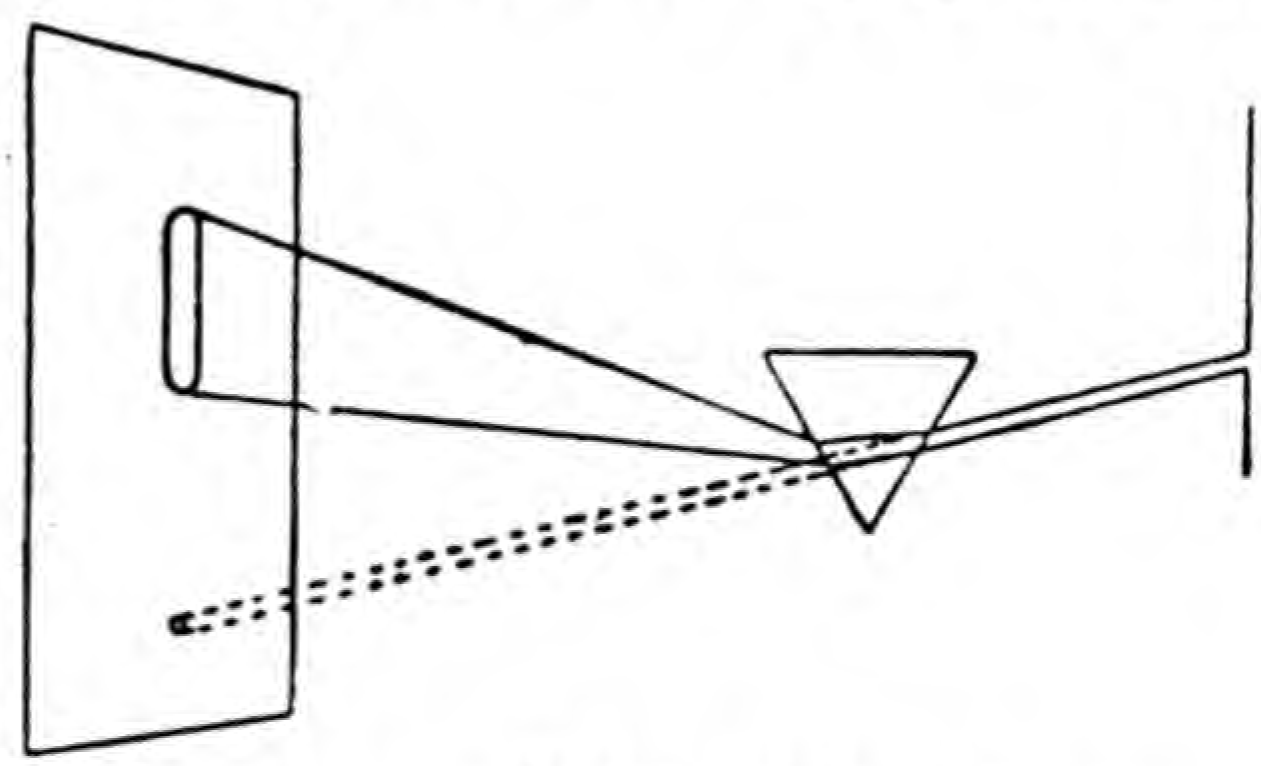


FIG. 107.—*The simple spectrum.*

The question is, of course, as to how the prism forms the spectrum. It is clear from the picture that each different colour seems to belong to a ray that has been differently bent by the prism. Newton did another experiment that made this quite plain. He let the first prism form a spectrum on a thin board in which was a small hole. This allowed only light of one colour to pass through, say the red, and he let this red light fall on a second prism. He found that the light was now not

[1] The actual prism was one having all three angles 60°, which is a so-called equilateral prism.

spread out by the prism, but remained a narrow beam. By moving the spectrum he then let the blue light pass through the hole, and found that it likewise was not spread out, but that it was more bent by the second prism than the red was. Think carefully now what these two experiments tell us. Firstly, light of one colour is not spread out by a prism, but bent; actually it is bent exactly the same amount by a prism no matter through how many other similar prisms it may have passed before. Secondly, lights of different colours are differently bent by a prism, the violet being bent most and the red least.

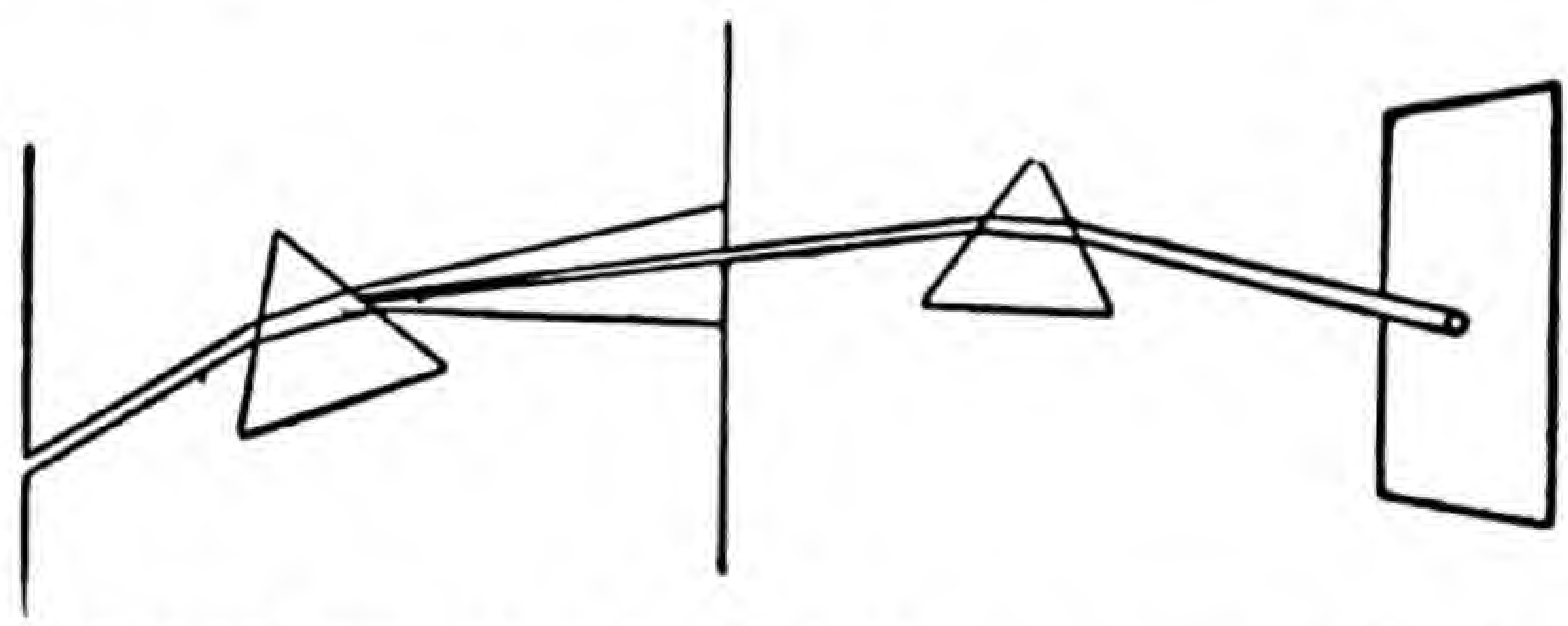


FIG. 108.—*Light of one colour is bent the same amount by the second prism as by the first.*

The spectrum is, then, formed in the following way. Ordinary white light is a mixture of all the colours of the spectrum, just as in music several notes which are sounded together make a chord. The difference is that a good ear can hear the separate notes of the chord, but a good eye cannot see the separate colours in white light. Here the prism comes in. Because the different colours are differently bent by the prism they are separated out and issue from the prism like a fan, with the least bent colour at one end and the most bent at the other. You can often see beautiful bands of colour thrown into walls or table-cloths from cut-glass stoppers, acting as prisms. Diamond

separates white light into a wider fan of colour than glass of the same shape does, which is why the precious stone sparkles with such beautiful reds, blues and other colours.

It may seem strange that white light contains all these colours, but Newton showed that if a second prism is put the other way up, so that it bends the rays in the other direction, all the colours which issue from the first prism are put together again by the second prism, and white light comes out.

The rainbow is a beautiful example in nature of the splitting up of white light by prismatic action. If white light enters a single drop of water it is bent, or refracted on entering it, is then reflected at the back of the drop and comes out again, on the same side of the drop as it entered. The two refractions produce colour, just as the refractions on entering and leaving the prism do. The red light which comes out makes an angle of $42\frac{1}{2}°$ with the light from the sun that falls on the drop; the violet light, more bent, makes a smaller angle of $40\frac{1}{2}°$. Suppose the sky full of raindrops, and that you are standing with your back to the sun. All drops on a certain ring opposite to you will send beams of light to your eye which make an angle of $42\frac{1}{2}°$ with the sun's beams that fall on them, but the beams which make $40\frac{1}{2}°$ will miss your eye. This ring, then, will appear red. Under this first ring, however, is another ring of raindrops which send beams making $40\frac{1}{2}°$ with the sun's beams to your eye, but the beams

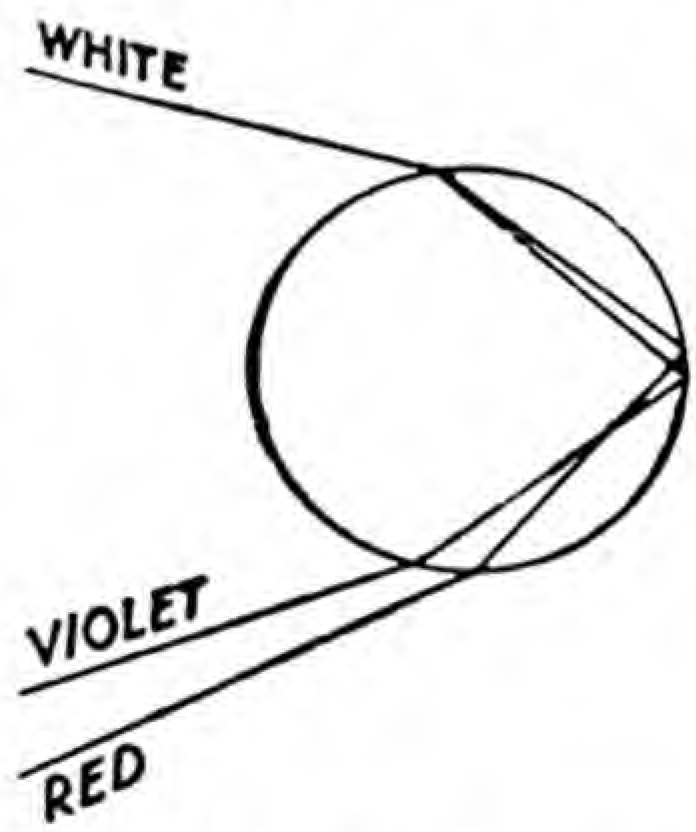


FIG. 109.—*How rays of light are bent by a drop. The violet in the white light is bent more than the red, and in a similar way all the different colours in the white light are separated out.*

from this ring which make $42\frac{1}{2}°$ will miss your eye. This ring appears violet, then. In between are the other colours. Fig. 110 illustrates the formation of the bow. All the drops send out light of all colours, but only drops on a ring of a certain size send light of a particular colour to the eye. It should now be clear why it is that to see a rainbow you must stand with your back to the sun, and why it is that the rainbow appears as an arch with you looking through the centre. On a clear summer day, if you stand with your back to the sun, and make a cloud of water drops in front of you with a garden hose, you can see quite a good artificial rainbow of your own making.

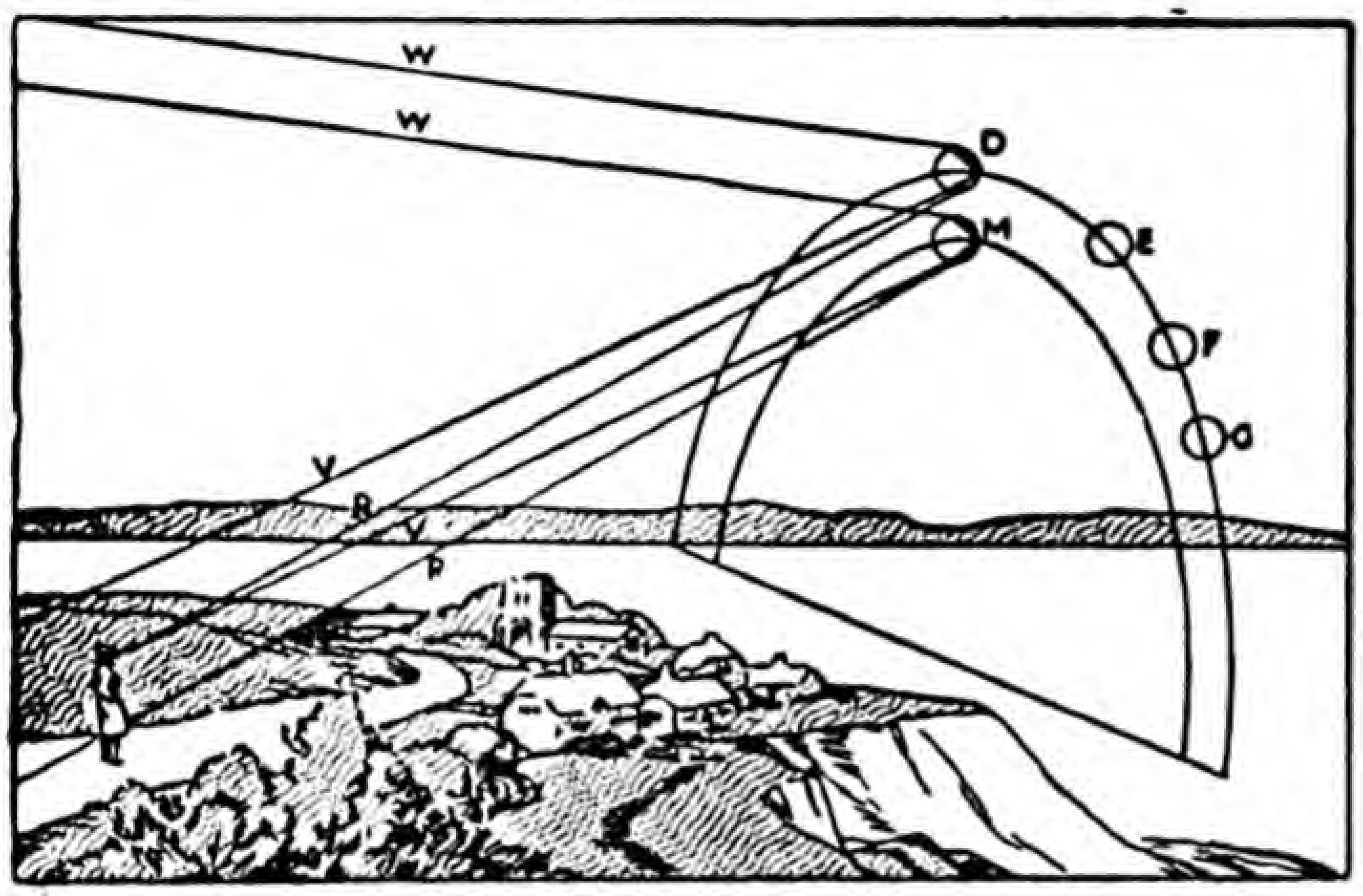


FIG. 110.—*A rainbow. The upper ring of drops sends red light into the eye, the lower ring of drops sends violet.*

Let us now think of a lens again. The image of a bright object giving out light is formed by the bending of the rays, as we have seen. If, however, the blue light is bent more than the red the focus should be nearer the lens, and if we have a white object we should expect the image to be coloured, owing to just such a separation as takes place with a prism. This, in fact, is the case. We take an electric lamp, put a deep red glass in front of it, and then form an image of the wires of the lamp with a single lens, noting carefully exactly where the paper has to be placed to get a sharp focus. If we now put a blue glass instead of a red one we shall find that the paper has to

be placed nearer. Or we can put the blue and the red glass edge to edge, so that the light from the upper part of the wires has to pass through the blue and that from the lower part of the wires through the red, and we shall then find it impossible to get both top and bottom of the wires sharply in focus at once. Finally, if we form an image of the wires without any coloured glasses we shall see that it is coloured at the edges, the red and blue showing most. This colour is troublesome, but as long as we use a simple lens we cannot get rid of it. However, by combining lenses made of different glasses a lens can be made which gives a white image. This is another reason why good lenses have to be built up of several parts. A compound lens which shows no colour with a white object is called achromatic.

We have seen that a prism splits up sunlight into a band of colour ranging from red to violet. At each end the band becomes faint, and shades off into darkness. This means that there are no rays beyond the violet which have any effect on our eyes, but it does not prove that there are no rays there at all. We know, for instance, that hot bodies which cannot be seen in the dark, such as a hot brick or piece of iron that is not hot enough to glow, can send out rays of heat that can be felt by the hand. Those rays of heat travel, like light, in straight lines, and can be reflected like light and refracted like light. They are, in fact, a kind of invisible light rays.

Special sensitive thermometers show that beyond the red end of the spectrum there are such rays, which produce a heating effect. They are called infra-red rays, and they have some very interesting properties. They are used in hospitals for curing certain diseases. They act upon certain special (not ordinary) photographic plates,

so that, for instance, an iron in a dark room, which is just not hot enough to be seen, can be photographed by means of the infra-red rays it sends out. Photographs can also be taken of distant scenes, and of planets, by the infra-red rays, by putting a sheet of deep red glass (or a sheet of deep red gelatine), called a light filter, in front of the lens, so that only the deep red and the infra-red rays get to the plate,[1] for the filter stops all the other colours. Landscapes photographed by the infra-red look very different from those photographed in the ordinary way. In the first place, leaves reflect the infra-red light from the sun very strongly, so that they appear very bright, and trees, for instance, photographed in full summer, look as if covered in snow. In the second place, while ordinary light, and particularly blue light, is scattered, or partly turned aside, by little specks of dust, and tiny water drops of mist, and even by the molecules[2] of the air, deep red and infra-red light is far less scattered in this way. The consequence is that distant objects, such as far hills, the light from which has to travel to us through air containing dust and droplets, look much clearer on an infra-red photograph than on an ordinary photograph, as can be clearly seen from the illustration. Infra-red rays pierce fog, and it is probable that in the future they will be much used for preventing collisions on sea and land. They can be detected by special instruments, as well as by photographic plates and delicate thermometers.

There are also rays beyond the violet, which are called ultra-violet rays. They act strongly on ordinary photo-

[1] The just visible deep red and the invisible infra-red run into one another in the spectrum, and have much the same properties.

[2] This word is explained in Chapter V.

graphic plates, and so such a plate, on which a spectrum is thrown, shows the band extending far beyond the place where it ceases to be seen by the eye. They are much more strongly scattered by air, dust and mist than visible rays, so that in a photograph taken by them even quite near things look misty, as can be seen from the illustration.

There are various kinds of infra-red and ultra-violet light, just as there are various colours in the visible spectrum. Some kinds of ultra-violet light produce sun-burn. These and other kinds are used for the treatment of certain diseases, especially rickets, and even healthy people find that it does them good to take off their clothes, and lie in the sun, or in ultra-violet light from certain special kinds of lamps. The beneficial effects of sunlight are largely due to the ultra-violet light in it. Remember that though you get hot in the sun, that is due to the visible yellow and red and the infra-red rays, while the sun "burn" is due to rays that produce no heating! Ultra-violet light helps to produce many chemical actions, and plays a large part in plant life.

Coloured bodies, such as stuffs and flowers, are not coloured because they add something to the white light that falls on them, but because they take something away from it. A deep red flower absorbs all the colours in white light except red with probably some orange and yellow,[1] and, therefore, the light which escapes is almost pure red. A blue stuff absorbs all the red and orange and yellow, and lets the blue escape, usually mixed with some green, indigo and violet. It is very interesting to put different coloured objects in coloured light. A lamp may be shut in a lantern, in front of which different coloured glasses, as pure as possible in colour, can be

[1] As we said on p. 147, unmixed spectral colours are seldom found.

placed.[1] If a good blue glass is used a red poppy will appear black, for it absorbs all blue light, and there is no red for it to throw back. In green light it will appear very dark, in yellow fairly bright, as it does not absorb all the yellow, and in red light brilliant red, for it does not absorb red at all. In strong red light a blue book will look jet black. Artificial light has far less blue in it than sunlight, or, in other words, it is much redder. As a result blue stuffs always look very dark by artificial light; they absorb everything but blue, and there is very little blue in the light that falls on them to escape. Red stuffs, on the other hand, look more brilliant by artificial light.

If you want to know what happens when we mix two paints we have to think of what will be left over after the two have each taken their bit from the white light. A blue paint absorbs, roughly speaking, the red, orange and yellow, as we have said: a yellow paint absorbs blue, indigo and violet. The only colour, then, which escapes the double absorption is green, and accordingly the mixed paint looks green. But if we mix blue and yellow *light*, not paint, by sending a blue beam and a yellow beam on to the same piece of white paper, which throws back the two lights mixed, the result is not green, but white, for, strangely enough, certain pairs of colours make a white which cannot be told, by the eye, from the white made up of all seven primary colours. The only way to tell the two whites apart is to use a prism, which would separate out the two colours in one case and the seven in the other.

[1] Coloured sheets of gelatine, as supplied, for instance, by the Kodak Company or the Ilford Company, are of purer colour than most coloured glasses are. They must not be allowed to get hot, or they melt.

CHAPTER V

INORGANIC CHEMISTRY

Different Branches of Chemical Science—The Balance in Chemistry—Elements and Compounds—Acids, Bases and Salts—The Manufacture of Acids—Pure Metals and Alloys

DIFFERENT BRANCHES OF CHEMICAL SCIENCE

CHEMISTRY is the science that deals with what substances are made of, and how they can be built up, broken down and changed from one to another. We gave some examples of chemical change in Book I. The science includes the consideration of a great number of different classes of substances and kinds of changes, and is divided up into different branches, to which such names as inorganic, organic, physical, colloidal and biological chemistry have been given. Any of these branches of chemistry may be applied to the manufacture of useful things, and then people speak of industrial chemistry.

Although, however, different kinds of questions and experiments in chemistry are considered to belong to different branches of the science, this is for convenience only, and the thing that is really important is to understand what the question or experiment means, and what it teaches us. It is often difficult to say to which branch a certain subject belongs, nor does it matter much in the end. To make this clear, let us think of a great store, with different departments for various things to eat, such as confectionery, grocery, meat, fish, vegetables and so

on; different departments for things to wear, such as suits, underclothing, boots and shoes, and so on; departments for toys, sports and games; garden things; and all kinds of other merchandise. This division into departments is a great convenience, and makes it easy to get what you want, for you usually know exactly which department to ask for. If you want a cauliflower you do not go to the underwear department, and if you want an ordinary shirt you go straight to the men's underwear department. But suppose you want a football shirt—you will not know whether to go to this department or to the sports and games department. You will have to ask, and the answer will depend upon which way the head of the store has decided, not upon any important principle. Which department you have to go to in the end will not matter to you, as long as you get your football shirt. To take further examples: golf shoes might be in the sports department or in the boot and shoe department, a child's racquet might be in the toy department or might be in the sports department: preserved fruits might be in the confectionery department or in the grocery department. Getting the thing you want is what you are interested in, and, while the department system helps a great deal in saving time all round, which department you buy them in does not affect, say, the taste of the preserved fruits, nor is it worth while arguing with the shopman that you think they ought to be in the confectionery, while they are actually in the grocery.

In the same way in chemistry, and in science in general, it is not worth arguing, in a doubtful case, whether a scientific problem ought to be considered to belong to one branch or to another branch—to inorganic chemistry, say, or to physical chemistry. The division of science

into departments helps to teach and to learn, but the things that really matter are the facts.

Now let us consider some of the main departments of chemistry. Inorganic chemistry deals with all sorts of non-living matter, such as metals, sulphur, chalk, salt, washing-soda, copper sulphate, the common acids (hydrochloric, sulphuric and nitric), and the gases oxygen, hydrogen and carbon dioxide, to name a few well-known substances, most of which we have mentioned before. To understand the ways of getting metals from the rocks and earth, called ores, which contain them we have to study a special branch of inorganic chemistry often called metallurgical chemistry.

Organic chemistry is concerned with the products of living things, animal and vegetable. The gas called methane, which comes from decaying vegetables; different alcohols, that are prepared from grain: glycerine, prepared from fats; sugars, from sugar-cane and from fruits; petroleum, formed in the earth from the remains of prehistoric animal and vegetable life—all these things are among the subjects of organic chemistry. In the next chapter we shall have more to say about what makes the difference between organic chemistry and inorganic chemistry. It is often very difficult to decide the borderline between organic and inorganic chemistry, and there was once a long lawsuit to decide whether calcium carbide was an inorganic or an organic chemical, because a certain law applied to organic chemicals only. From the scientific point of view it really does not matter, as we have said, which you call it. The calcium carbide is the real thing.

Physical chemistry deals with processes into which both chemistry and physics enter, such as electro-plating,

a process in which electricity, the study of which is part of physics, leads to chemical changes. The effect of light on chemicals, and the way in which one chemical dissolves in another, are further examples of things that are studied in physical chemistry.

Colloid chemistry deals with things like glues, jellies, india-rubber, gums, and white of egg. These substances do not solidify in clean, sharply shaped crystals, as do, for example, salt, sugar and washing soda: many of them have a sticky or jelly-like nature. They take up water and swell, and the amount of water in the solid may be changed at will, as anybody who has made a jelly knows. In this way they are different from inorganic solids like copper sulphate crystals, for instance, which contain water in a fixed amount—36 grams of water in every 100 grams of substance, in the case of the blue crystals of copper sulphate.

Liquids which consist of tiny specks of one substance floating in another substance, the specks being too small to be seen with the naked eye or to sink, are also studied in colloid chemistry. Milk is such a liquid, for it is a weak, watery solution of salts and certain other substances, with little particles of fat, a few ten-thousandths of an inch across, floating in it. Butter is made by causing the fat particles to stick together in a solid mass, leaving the liquid behind: it is also a colloidal substance. So is blood.

The presence of the little particles in colloidal solutions can be prettily shown by passing a strong beam of light, say a cone of light from a lens, into clear water in a glass-sided tank. As we have said in Chapter IV, seen from the side the beam will be hardly visible. If, however, a teaspoonful of milk is put into the water, the beam is at

once seen as a bright cone, called the Tyndall cone, after the man who first drew attention to what this kind of experiment shows. The particles of fat in the milk scatter the light out sideways to the eye. Things that dissolve in the ordinary way do not do this: if you dissolve a little *clean*[1] salt or soda in the water no cone will be seen.

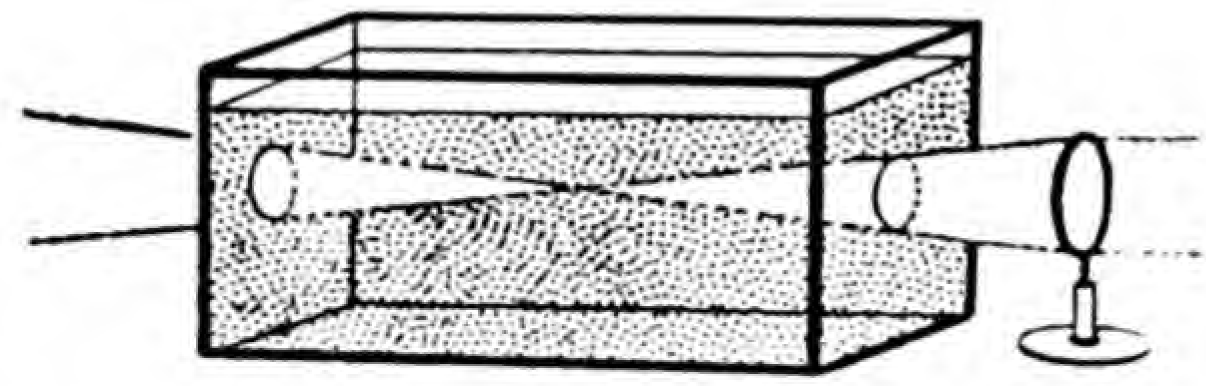


FIG. 111.—*The Tyndall cone. The rays of light are thrown out sideways by little particles in the liquid*

Biological chemistry, or biochemistry, as it is generally called, deals with the chemical changes that go on in the actual living body, the chemistry of digestion, of blood, of the brain, and so on. Most of the substances which occur in the body are colloids, so that colloid chemistry is also important in helping us to understand living animals from the chemical point of view. All the things in the body are terribly complicated when considered as chemicals, and biochemistry is one of the most difficult, as well as one of the most interesting, parts of chemistry.

You will see, then, what a lot of different things are included in the study of chemistry. All the different branches that have been mentioned are not clearly separated, but run into one another, just as the different sciences do. These difficulties always come in when we sort things into classes, and, as we have said, it does not matter into which class we put doubtful cases.

[1] Dust in the substance will produce a cone. It is best to dissolve the soda or salt in water first, filter it, and then add the clear liquid to the water in the tank.

THE USE OF THE BALANCE IN CHEMISTRY

The chemistry of to-day has been built up largely by the careful weighing of the substances that act on one another, and a good balance is absolutely necessary in every chemical laboratory. The kind of instrument used is shown in Fig. 112. The two pans are hung from sharp knife-edges, so that the point at which they

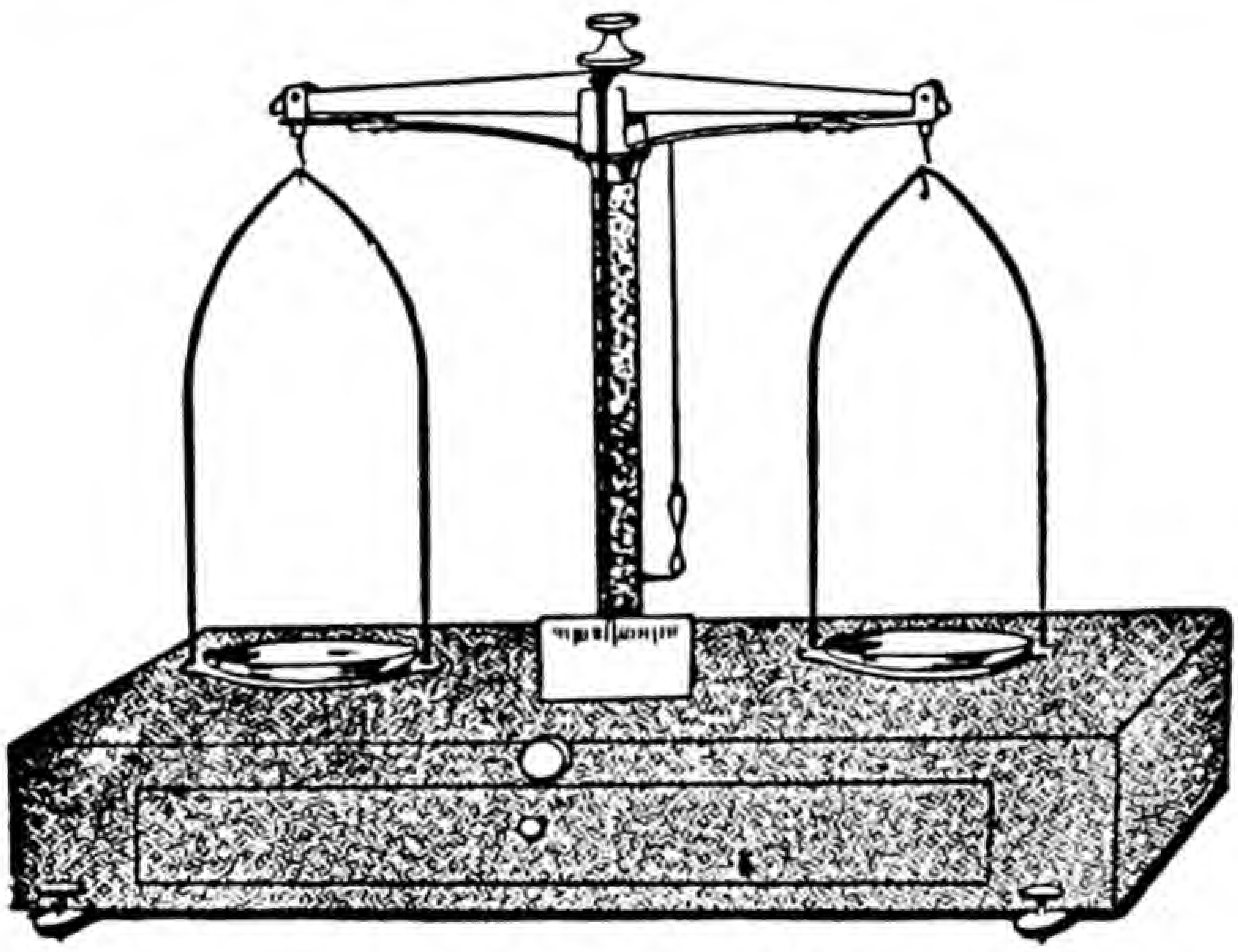


FIG. 112.—*A chemical balance.*

pull on the beam is always exactly the same. The pans rest on the floor of the balance: when a weighing is being made the knob in front is turned, which lifts a central rod. This rod carries a knife-edge on which the beam balances, so that the pans are now free to dip. A long pointer shows whether the balance is swinging equally to either side. The whole balance is in a glass case which is kept closed during a weighing, so that no current of air may blow one or the other pan a little down. Either pan can be taken off the knife-edge when required. A

good school balance can weigh to one hundredth part of a gram, but for the most delicate work small balances are made which weigh things not heavier than 20 grams to within one millionth of a gram or so. Such accuracy is largely a question of the proper making of the knife-edges, and the writers know of only one firm who can make a balance of this accuracy really well. What little details lead to success! The man who can make and adjust a better knife-edge than anybody else can sell his skill all over the world.

We will now consider some changes in weight that take place during chemical change. Suppose that we

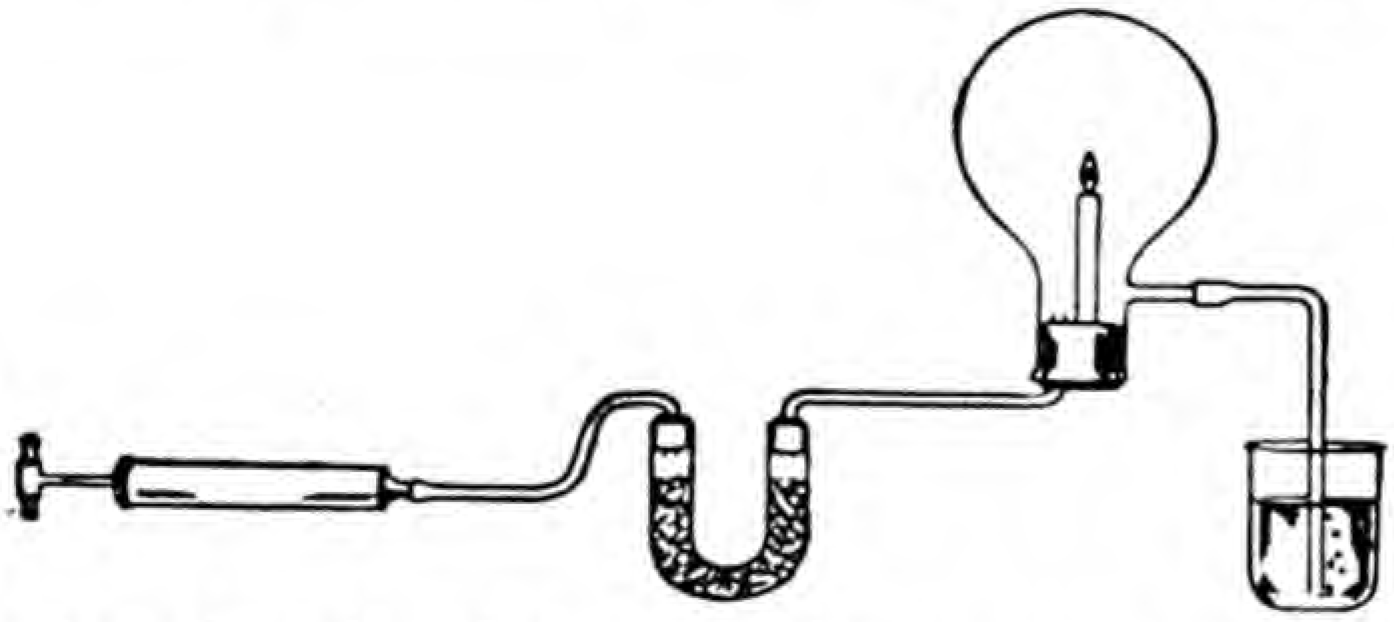


FIG. 113.—*Proving that burning a candle in air produces carbon dioxide.*

burn a piece of candle: apparently some of the candle disappears and is destroyed. If we weigh the candle after burning it will, of course, weigh less than before. Certain substances have, however, been formed during the burning, and have escaped. Water, for instance, is formed: if we hold a round flask full of cold water over the flame it becomes covered with dew. Carbon dioxide is formed. We know from Book II how to test for this gas: it turns lime-water milky. We set a small candle to burn in a flask, as shown in Fig. 113; there is a tube passing through a hole in the cork, and another tube leads from the neck of the flask. To the latter we fasten a further

glass tube which dips under the lime-water in the vessel. We also arrange a football pump so that we can blow air through the flask: between pump and flask we put a tube full of pieces of caustic soda, to take up the carbon dioxide that is in the air, and make sure that there is none of this gas in the air that enters the flask. If now, with the pump, we blow very gently through the flask, the air that bubbles through the lime-water will make it milky. If the candle is not lit, the lime-water keeps clear. This proves that the burning of the candle in air produces carbon dioxide. If we blow direct into the lime-water with our mouth, it goes milky, because we know that our breath contains carbon dioxide, formed by a kind of burning that goes on inside us. (See Book II.)

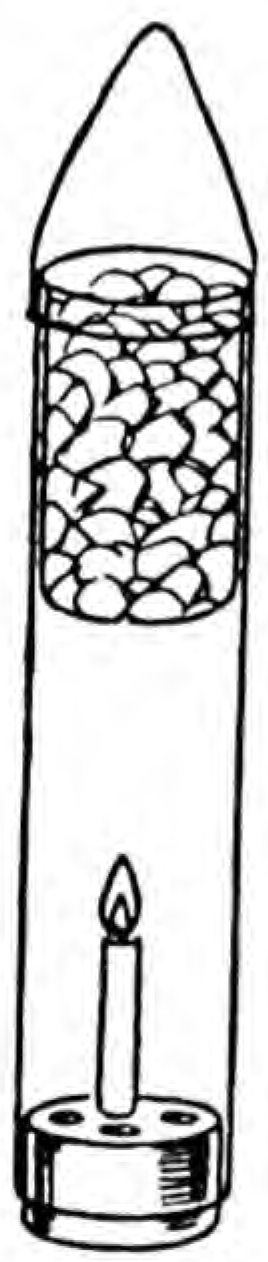


FIG. 114.—*One way of catching the carbon dioxide from a burning candle.*

To see if anything in the lighted candle has really disappeared we must weigh the carbon dioxide and the water formed from the wax in the process of burning. We can do this by making use of the fact that the substance just mentioned, generally called caustic soda (the proper chemical name is sodium hydroxide), absorbs both moisture and carbon dioxide. The following experiment is often described in books. A candle is arranged in a lamp glass, as shown in Fig. 114, with holes in the cork at the bottom to let in air, and pieces of caustic soda, resting on a metal net, at the top. The whole arrangement, with the candle unlit, is hung on an arm of a balance, and weighed. The candle is then quickly lit and replaced. As it burns, the carbon

dioxide and water, in the form of vapour, rise with the hot air, and are caught by the caustic soda. Very soon the arm of the balance begins to sink, so that we have to keep on adding small weights to keep the balance level. This experiment is said to show that the result of burning a candle is a *gain* in weight, if we catch all the products of burning.

It is true that there is a gain in weight, but the experiment is not a good one, for even if the candle is *not* lit, there will be a gain in weight as time goes on, owing to the fact that the caustic soda takes up moisture and carbon dioxide from the air, which, as we know, contains both. An experiment carried out with everything the same except the one particular feature whose effect you are trying to measure (in this case the burning candle) is called a *control* experiment, and control experiments play a large part in science, as they show us if we are really measuring what we think we are. For instance, if you want to see whether a fertiliser helps particular plants to grow, it is little use putting some in the earth where the plants are growing to see if they flourish, unless side by side you have similar plants, growing in the same kind of earth, receiving the same amount of water and the same light, but with no fertiliser. Your plants without fertiliser supply the control experiment.

In the case of the candle the control shows that we cannot be sure that the gain in weight was really due to the burning candle, if the experiment is carried out in the way described. A rather more troublesome arrangement is necessary. The candle is put in a large bottle of the kind shown in Fig. 115, with a tube at the bottom and one at the top. To the one at the top are attached two tubes, B and C, containing small pieces of caustic soda,

and to the one at the bottom a similar tube A, as drawn. Then if air is drawn over the burning candle, in the direction shown by the arrows, tube A will make sure that the air coming in has no moisture or carbon dioxide in it, and tube C will make sure that no moisture or carbon dioxide gets in from the other side. Any gain in weight in tube B must, then, be due to moisture and carbon dioxide from the candle. To draw the air through the apparatus use may be made of what is called an aspirator, which is simply a large bottle of the kind in which we have put the candle, provided with a tap. If

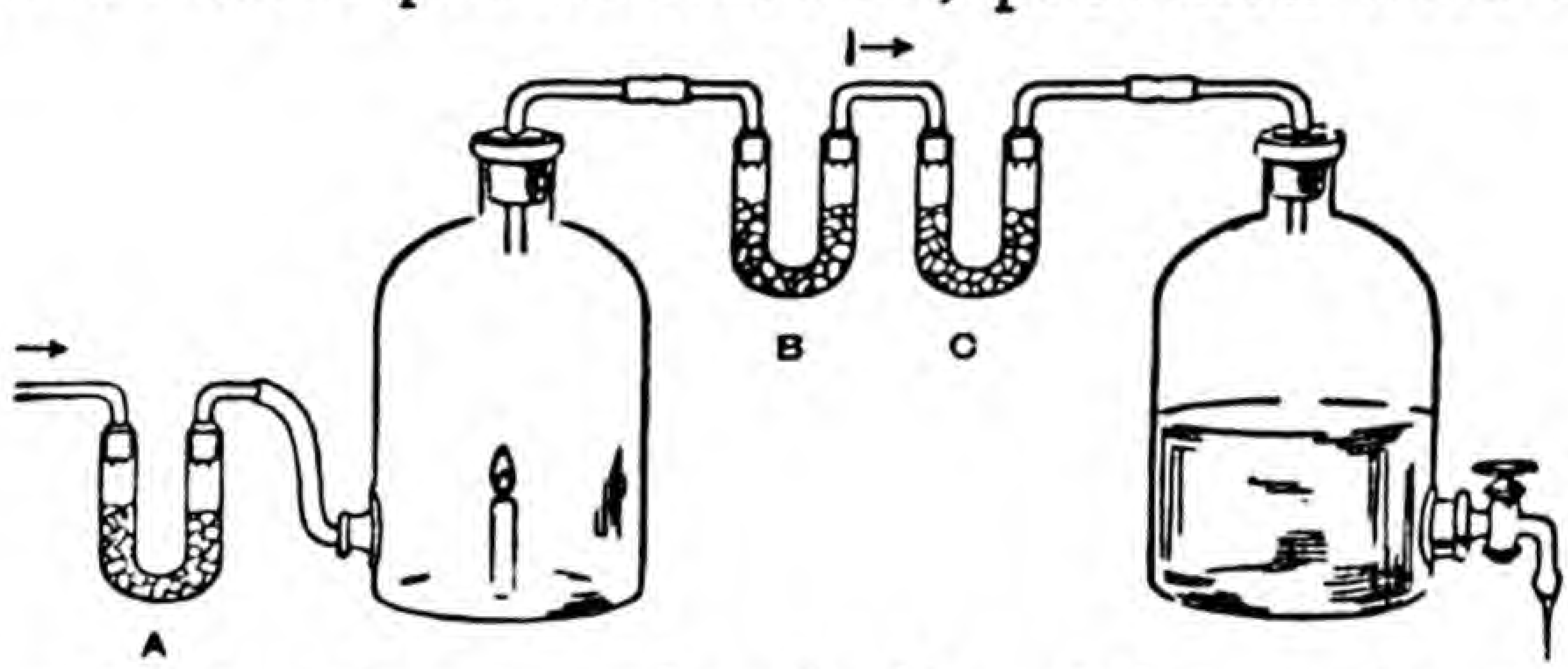


FIG. 115.—*Proving that the carbon dioxide weighs more than does the piece of candle that has been burnt.*

the bottle is filled with water and the tap opened, then, as the water runs out, air must come in to take its place through the tube at the top.

To carry out the experiment the unlit candle and the tube B are weighed, the openings of B having been first closed by little corks, to prevent the caustic soda from taking up anything from the air. Tube B is then placed in position, and the candle is lighted and quickly put into the bottle, which is tightly corked. The aspirator is started by opening the tap, and the air from the burning candle, mixed with the moisture and carbon dioxide, passes through tubes B and C, and fresh air takes its place. After

some time we quickly remove the candle and blow it out, and then take tube B and stop the ends with the same little corks as befcre. If now both candle and tube B are weighed again it will be found that tube B has gained far more than the candle has lost. A control experiment, with the candle not lighted, should show no gain in weight of B.

We know that the candle requires air if it is to burn. The reason that there is a gain of weight in burning, if all the products are considered, is that the candle uses up some of the oxygen in the air, as we learnt in Book II. Water, as we know, is made of hydrogen and oxygen. Carbon dioxide is made of carbon and oxygen. The candle grease is a compound which contains both carbon and hydrogen, while the air contains oxygen. The stuff caught by the caustic soda is not only stuff that has come from the candle, but also a lot of oxygen from the air joined to the carbon and hydrogen of the candle grease in chemical combination. The gain in weight on burning was also shown in the experiment on magnesium described on page 11 of Book II. This was an easier experiment because, with magnesium, the product of burning is not gases, but a solid, and so can be collected without trouble.

We cannot find, then, what is the weight of the stuff that has left the candle when it burns unless we can find out, or allow for, the weight of oxygen used up. Of course if we burn the candle with air in a completely closed vessel the oxygen taken out of the air will go into the carbon dioxide and water, but no oxygen will enter or leave the vessel. In this way we can find out if a change of weight really takes place on burning, when we consider *all* the substances used up and *all* the substances formed.

The easiest way to burn something in a completely closed vessel is to use matches. We take a flask, as large as can conveniently be weighed on our balance, and fit a glass rod tightly through the cork. To the rod we fasten two or three matches with a piece of wire, so that the heads just touch the side of the flask, as shown in Fig. 116. The whole is then weighed. By heating the side of the flask with a flame we make the matches catch fire: they burn for a short time, and then go out. When the flask has cooled down we weigh it again, and find that there is no change in weight. Some part of the matches appears to have vanished, but really has combined with the oxygen in the air sealed up in the flask. Chemical change has taken place, but nothing has entered or left the flask.

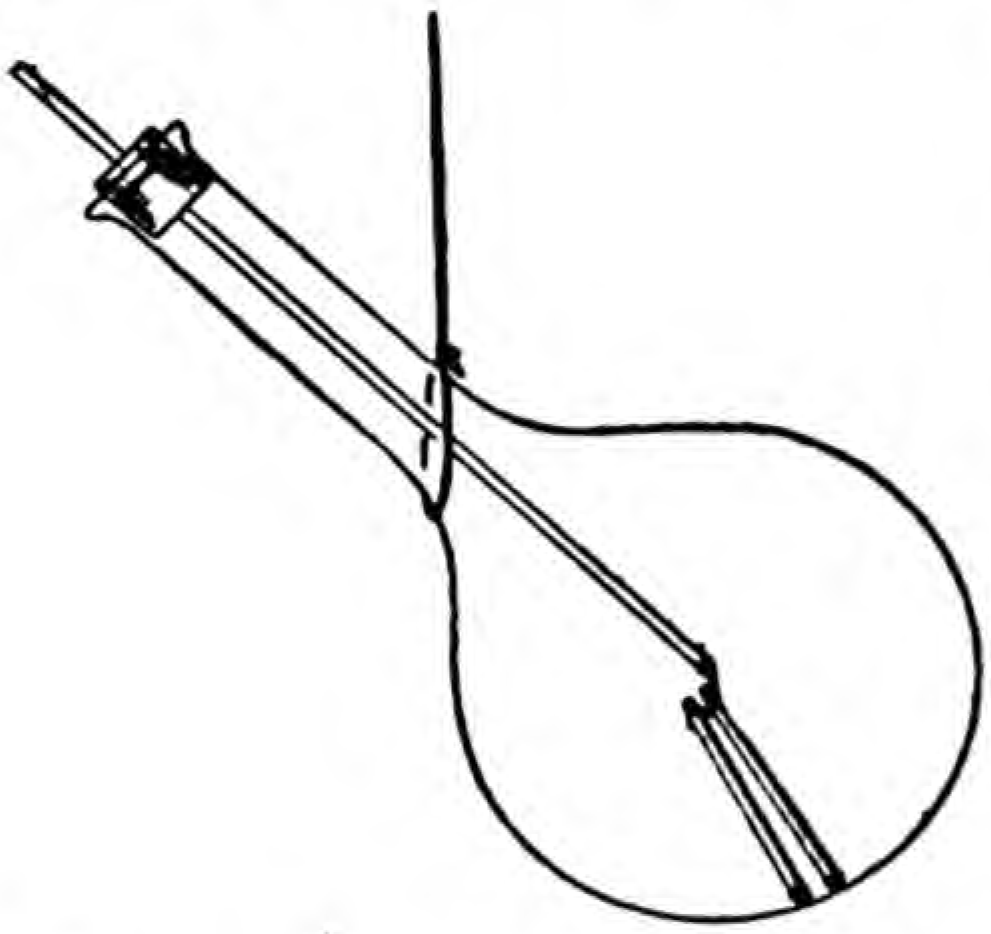


FIG. 116.—*To burn matches in a closed vessel.*

Another experiment which proves the same thing can be carried out with phosphorus instead of matches. A small piece of phosphorus is put in a tightly corked flask, and the whole is weighed. The phosphorus can then be made to burn by heating the flask just where it lies. Once more the sealed flask will be found to weigh the same after the combustion as before it.[1]

[1] See also the experiment with phosphorus in Book II, p. 6. Phosphorus catches fire so easily that it must be handled very carefully. It should be kept under water, and must be handled with tongs, not with the fingers. For the experiment a small piece may be cut off under water, and then dried on blotting paper.

When anything burns, then, there is no change of weight when the ashes and gases formed and the oxygen used up are taken into account. Nothing in the candle or in the matches or in the air is really lost: when burning occurs the substances which take part in it just reappear in another form, but still weigh the same.

Burning is only a particular kind of chemical reaction, but what we have just learnt about nothing being lost in burning is true for every chemical reaction. We can, for instance, put a little of one chemical, contained in a test tube, into a corked flask containing another chemical, as shown in Fig. 117, and weigh it. We then tilt the flask so that the two mix and react. If we then weigh the flask again we shall find no change in weight. We may, for example, put a little ferric chloride solution in the tube, and potassium ferrocyanide solution in the flask: when these mix a deep blue precipitate is formed. Or we may put a little silver nitrate in the tube, and hydrochloric acid in the flask, which gives a thick white precipitate in mixing. Or we may put a little copper in the tube, and nitric acid in the flask, which should be tightly corked. When the copper is tipped into the acid the flask will be filled with deep red fumes, but the amount of copper should be very small (not more than a quarter of a gram in a 500 c.c. flask), or so much red gas will be given off that it will blow the cork out of the flask, or burst the flask.[1] No matter what the chemical reaction, if we let nothing enter

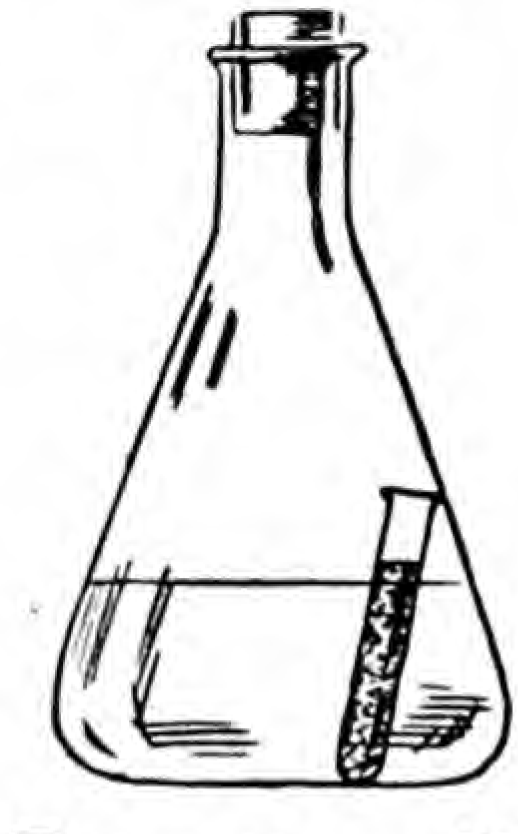


FIG. 117.—*To produce a chemical reaction in a closed vessel.*

[1] It is best to use a round flask for this experiment, as it is stronger than a conical one.

from outside, and let nothing escape in the form of gas (or otherwise), the weight before combination takes place will be exactly the same as the weight after combination.

When a cup is silver-plated by electricity, silver which was in the clear solution comes out and sits on the cup, but the silver weighs just the same, and was there all the time, as the balance, not the eye, tells us. It is, then, impossible by chemical action to destroy matter: we can only rearrange it. This great rule is called the *Conservation of Matter*. We are always using it in chemistry. If, for instance, we know that a solid substance when heated gives off a gas, we can tell how much gas has been set free by weighing the solid before and after heating: we need not weigh the gas. If we bubble carbon dioxide into a strong solution of potash, which absorbs it completely, we can tell how much carbon dioxide has passed by weighing the vessel containing the potash before and after bubbling. It is because the conservation of matter is true that the balance is always being used in the chemical laboratory. In big laboratories there is always a special Balance Room, with balances of different degrees of accuracy all arranged on firm tables.

Elements and Compounds

We saw in Book I that, if we put a piece of bright iron into a solution of blue copper sulphate, a coat of copper appears on the iron. The copper sulphate, then, must consist of copper and something else: it is actually a compound of copper, sulphur and oxygen. We may ask if the iron and the copper are also compounds: can we take something out of them, and leave behind something which is not iron or not copper, as the case may be?

The answer is that copper and iron are simple substances, which cannot be broken up into other chemicals. The sulphur and oxygen in copper sulphate are likewise simple substances, which are not made of other things. Such simple substances are called *chemical elements*, or simply *elements*. There are about ninety elements, which is not so many considering the millions of different substances known to chemistry; and, of these ninety, thirty or so are very rare, and hardly ever seen or handled, even by most chemists.

Among elements which are familiar are the metals, aluminium, chromium, copper, gold, platinum, iron, lead, nickel, silver, tin, zinc and the liquid metal mercury: there are other metals, such as cobalt, manganese and vanadium, which are very important for making special steels; and tungsten, which is used for the wire filaments of electric lamps, since its melting point is so high (3,500° C., while that of platinum is 1,710° C. and that of iron 1,530° C.). Sodium and potassium are very common as compounds, but not so well known in the uncombined state: they are soft, white metals which speedily combine with moisture or oxygen, and so have to be kept under oil. They are easily cut with a knife, and are lighter than water. Calcium is another metal which is rarely seen alone, but which is common in compounds such as limestone rock, and substances found in bones and milk. The pure metal is white, and about as hard as tin.

Carbon, sulphur and phosphorus are non-metallic elements: the first two are common enough, and the last is often seen in the laboratory, and has already been mentioned. Among the gases which we have talked about, hydrogen, oxygen, nitrogen are elements, but carbon dioxide is a compound made of the elements carbon and

oxygen, and the red gas from copper and nitric acid, called nitrogen peroxide, is made of nitrogen and oxygen. Other gases will be mentioned later.

It will surprise many people to know that oxygen is by far the most abundant element. Nearly half of everything in or on the crust of the earth[1] consists of oxygen, which occurs in all the common compounds. Water, of course, is mostly oxygen as far as weight goes (see Book I, p. 150). Many kinds of rocks are more than half oxygen. The other chief substance combined in rocks and stones is the element silicon, which is a substance which is something like a metal and something like carbon. Clean sand is little particles of a compound of silicon and oxygen which we find in big masses as flint; granite, and rocks of the granite kind, also contain oxygen and from twenty to thirty per cent. of silicon. Glass is made of sand, among other things, and contains much silicon, so we are always handling compounds of this element. It is the second most abundant element in the earth's crust, forming rather more than one quarter of the weight of the whole. Aluminium comes next: it occurs largely in clay and in many rocks, usually combined with oxygen. Then follow iron, calcium, sodium, potassium and magnesium. These eight elements make up together over 98 per cent. of the earth's crust: all the other eighty or so have less than 2 per cent. between them.

Very few of the elements are found free—that is to say, in an uncombined state—in nature. All the eight common

[1] By the crust we mean the surface layers, that is, the air, waters and solid surface of the earth down to, say, ten miles deep There is, by comparison, so little living matter, as far as weight goes, that it makes no difference whether we reckon it in or not. Living matter is just a thin scum at the surface.

ones are found only in compounds, if we leave out the free oxygen mixed in the air.[1] Certain metals occasionally occur pure. Everyone has heard of the finding of nuggets of gold: copper and mercury are also found sparingly in the free state. Natural sulphur is found abundantly in volcanic districts. These are trifling exceptions: practically all the things we meet in nature are chemical compounds, and, except for the metals won by man from ores, most of the things around us in our homes and cities are chemical compounds.

We have spoken in Book I of what is meant by a chemical compound, and especially of how the proportions of the different things in a particular compound are always the same. In dry white copper sulphate,[2] say, made by different people, the percentages by weight of copper, oxygen and sulphur are always the same: in the ordinary blue copper sulphate we have, in addition, water built into the crystals, but here again the proportion of water is always the same. If you put a large quantity of crystals of copper sulphate in a little water, some of them will dissolve, but those that remain undissolved will not take up any more water than they already have. In water itself the proportions of oxygen and hydrogen are always the same: in carbon dioxide there is always $\frac{3}{11}$ of carbon and $\frac{8}{11}$ of oxygen by weight. For instance, the carbon dioxide in our breath and that formed by the burning of a candle and that formed by the action of acid on marble (see Book I, p. 40), all have exactly the same composition. That is to say, they not only contain

[1] Meteors, or "shooting stars" as they are called, which are pieces of stuff coming into our atmosphere from outside, often consist, however, of pure iron.

[2] See Book I, p. 133.

carbon and oxygen, but the proportion by weight of carbon to oxygen is always precisely the same. This rule, that the composition of a pure chemical compound is always the same, is called the *law of definite proportions.*

This does not mean, however, that only one kind of compound can be formed of two elements. Oxygen and hydrogen can combine to make a chemical in which there is just twice as much oxygen, to the same weight of hydrogen, as there is in water. It is called hydrogen peroxide, and is nothing like water in its chemical behaviour. Its density is 1·46 instead of 1 gm. per c.c., and when it is added to potassium iodide with a little starch in it a deep blue colour is produced, whereas water produces no change. It is also well known for its bleaching properties, and turns dark hair to the particular colour known as peroxide blonde, which water will not do. Hydrogen peroxide is also a good disinfectant, as it kills germs and other small living things. In all hydrogen peroxide the proportions of oxygen are fixed, just as they are in water, but they are different proportions. The proportions in the two substances are, however, very simply related, as we have just said.

Again, carbon and oxygen can combine to form a gas called carbon monoxide, in which there is just half as much oxygen as there is, to the same amount of carbon, in carbon dioxide. Carbon monoxide, which is a very poisonous gas, is often formed in burning when there is a shortage of oxygen. Carbon dioxide will not burn at all: carbon monoxide burns with a pale blue flame,[1] taking up more oxygen and becoming carbon dioxide. It

[1] The blue flame that can often be seen over the fires made of coke in a bucket, such as night watchmen use, is due to carbon monoxide burning to carbon dioxide.

does not, however, add to itself sometimes a little more oxygen, sometimes a little less, but always takes into combination just as much oxygen as it already has, so that when it becomes carbon dioxide the amount of oxygen with which the carbon is combined is precisely doubled.

To take another example, there are two important oxides of iron, one called ferrous oxide, which is black, and the other called ferric oxide, which is red, and occurs in nature as the iron ore called hæmatite (see p. 191). To a given weight of iron there is precisely $1\frac{1}{2}$ times as much oxygen in the red oxide as in the black, or, saying the same thing another way, the proportions of oxygen in the two oxides are as 3 to 2, once more very simple figures.

Sometimes, then, we may have more than two different compounds of two elements, but they are always quite distinct in properties, and the weights of the one element, say A, which unite with a fixed weight of the other element, say B, bear very simple proportions to one another, such as 1 to 2, or 3 to 2. This is called the *law of multiple proportions*.

There is a simple explanation of the two laws, that of definite proportions and that of multiple proportions. An element is made up of very tiny parts, which are called atoms. These atoms are much too small to be seen; even with the most powerful microscope a piece of copper, for instance, looks quite continuous, like a piece of marble, and not like a packet of peas, which it really rather resembles. In spite of the fact that they cannot be seen, modern science, by very wonderful experiments that are too difficult to describe here, has proved quite clearly that the atoms exist, and that a row of about a hundred million atoms laid side by side would

be an inch long. Atoms of different elements are of different sizes, but not very different. In the same way, although birds' eggs are of different sizes, we can say that *about* 40,000 eggs side by side would reach a mile.

If we could magnify a copper wire, of the thickness of a hair, until it was big enough to fill a wide street, the atoms of which it is made would be the size of small specks of dust. This means that in any piece of matter which we can see there are a prodigious number of atoms. Consider, for instance, a little bubble of oxygen, of about the size of the bubbles of carbon dioxide that you see in gassy drinks. If every one of the three thousand million people in the world started to count, and could count three hundred a minute, and counted day and night, it would take them four months to count all the atoms in this bubble.

An atom is the smallest possible piece of an element: we cannot have half an atom. All the atoms of a particular element are alike and chemically the same. The atoms of different elements have different weights.

Now let us consider what happens when two elements, say carbon and oxygen, combine. The atoms of carbon join up with the atoms of oxygen. We may have them joining one to one, one atom of carbon to one of oxygen. Such a pair is the smallest possible piece of carbon monoxide, which is written CO. The C stands for one atom of carbon, the O for one atom of oxygen. The smallest possible piece of a compound is called a *molecule* and it is made up of *atoms* of elements. You can remember this by the old rhyme:

Two little *atoms*, coming home from school,
Fell into each other's arms, and formed a *molecule*;

although you must also remember that most kinds of molecules are made up of more than two atoms. The atoms correspond to bits of Meccano, say: with only two different kinds of bits, or atoms, you can only build a very simple structure, or molecule.

An atom of carbon may, however, join to *two* atoms of oxygen; we then have a molecule of carbon dioxide, written CO_2, spoken cee-ōh-two, which is what chemists, in speaking, generally call carbon dioxide for short. This is a molecule of three atoms. But clearly we cannot have an atom of carbon joined to a little more than one atom of oxygen, or a little less than two, because atoms can neither be made a little heavier, nor whittled away. As they are the smallest bits possible we can only have one, two, three and so on—whole numbers of them. Marble, which is calcium carbonate, is written $CaCO_3$, Ca standing for one atom of calcium. This is a molecule of five atoms, three different kinds of atoms, but three of one kind. If this is strongly heated the CO_2 comes off and CaO (calcium oxide, also called quicklime) is left.

With our two different oxides of iron (the chemical symbol for iron is Fe, from the Latin *ferrum*, which means iron) we have, in one case, 2 atoms of iron joined to 3 atoms of oxygen, Fe_2O_3, and in the other 1 atom of iron joined to 1 atom of oxygen, FeO (which gives the same proportions by weight as 2 atoms of iron joined to 2 atoms of oxygen). This explains why the weights of oxygen are as 3 to 2 in the two compounds.

Our two laws, then, are simply explained if we remember how atoms join together to form molecules. In any piece of a definite compound that is big enough to see there are millions of millions of millions of molecules, but they are all built up in the same way. In each molecule

there are only a few atoms of each kind of element: in many kinds of molecules only one atom of each kind. Another compound may consist of the same elements, but the numbers of the atoms in each molecule will then be different.

Finally, we want to remember that the atoms of different elements have different weights. An atom of oxygen weighs 16 times as much as an atom of hydrogen. As in water there are two atoms of hydrogen to one of oxygen —water is written H_2O in chemical symbols—there will be 8 times as much oxygen by weight as there is hydrogen. In hydrogen peroxide, written H_2O_2, there will be 16 times as much oxygen as hydrogen. An atom of carbon weighs 12 times as much as an atom of hydrogen: you can now work out the proportions, for carbon monoxide, CO, and carbon dioxide CO_2. They have been already given, so you can check whether you are right.

Acids, Bases and Salts

A very important class of chemical substances is the acids. We have come across certain of them already: for instance, we have learnt that hydrogen is prepared by the action of sulphuric acid on zinc, and carbon dioxide by the action of an acid on marble. Any acid will do for the preparation of carbon dioxide in this way, and it makes a good experiment to put some pieces of marble (or some pieces of sodium carbonate) in four different test tubes, and to add respectively dilute hydrochloric, sulphuric, nitric and acetic acids. The gas can be led away with the help of a cork and bent tube. In all four cases it turns lime-water milky, is heavier than air, for it can be collected by its settling in a cylinder (collected by

downward displacement, as chemists say) and at once puts out a burning match lowered into it. It is clearly carbon dioxide.

The four acids just named are those most often met with. Hydrochloric, sulphuric and nitric are inorganic acids which can be prepared, as we shall see, from substances found in the earth, and are therefore often called the mineral acids: acetic acid is an organic acid. There is a lot of acetic acid in vinegar, which is made either from wine or from malt. Wine is, of course, made from grapes, and malt from grain, so that the acetic acid in vinegar is clearly of vegetable origin. The acetic acid which chemists use is not made from vinegar, for that would be too expensive, but from wood. Oxalic acid, which is popularly called acid of sugar (because it can be made from sugar and nitric acid), is another organic acid, commercially made from sawdust. It is contained in many plants, such as wood-sorrel, to which it gives a pleasant bitter taste, and there is a lot of it in rhubarb leaves. It is a powerful poison in any quantity, and during the Great War several people were poisoned by eating boiled rhubarb leaves instead of spinach, on the advice of that dangerous class of persons, well-meaning busybodies.

The acid which lemons contain is citric acid: in fact lemon juice is 6 per cent. citric acid. The crystals sold as lemonade powder consist mainly of citric acid and sugar. You will see, therefore, that some organic acids, like oxalic, are poisonous, while others, like acetic and citric, can be consumed without harm.

What properties in common have all acids, inorganic and organic, that makes us call them all by the same general name? One we have already seen: when added to marble they all produce carbon dioxide. Further,

they all contain hydrogen. When hydrochloric and sulphuric acid act on zinc the hydrogen is replaced by the metal and comes off in bubbles, as we have seen, but with nitric acid the hydrogen is attacked, before it can get away, by the oxygen which is in the nitric acid, and is turned to water.

FIG. 118.—*Lichens on a tree.*

All acids turn a vegetable substance, called litmus, red. Litmus is a dye manufactured in Holland from certain special kinds of lichens. Lichens (pronounced "li-kens," with the i long, as in "like") are peculiar little flat plants found growing on rocks, old wooden posts, trunks of trees and such-like places. They are of various colours, and in earlier times were widely used for preparing dyes for dyeing cloth. The home-spun cloth of Scotland and Ireland is still dyed with lichens. The litmus used for chemical testing is usually supplied as litmus paper, which is rough unglazed paper full of the dye; it is

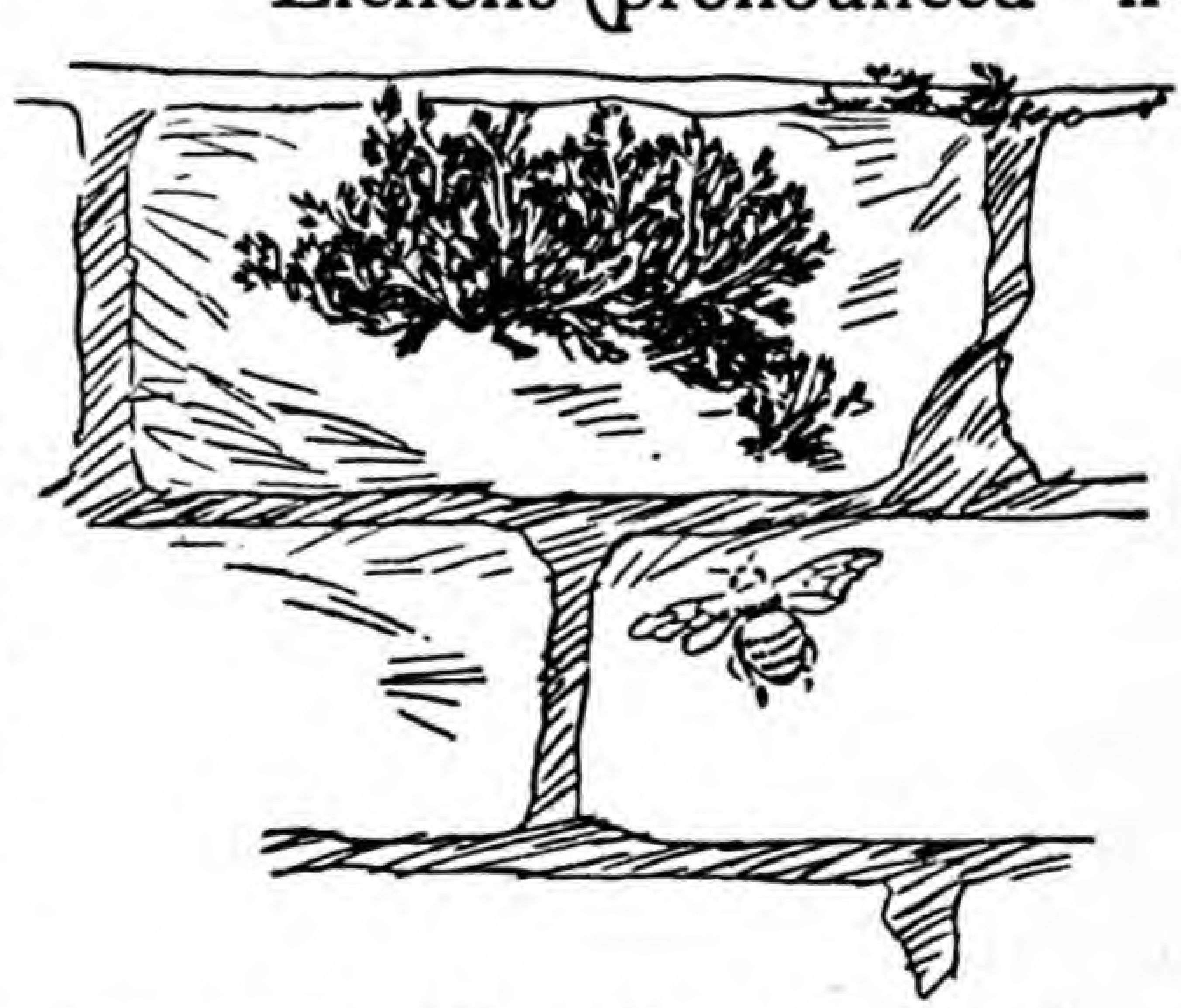


FIG. 119.—*The lichens from which litmus is made.*

either red or blue in colour. A tiny drop of the liquid to be tested is taken with a glass rod and put on a slip of the blue paper: if it is an acid a red spot forms at once. If it is put on a slip of the red paper there is no change of colour.

All acids have a sharp "acid" taste. If you want to test this, add a little acid to plenty of water and put a small drop of the very weak solution on your tongue. Dilute hydrochloric acid is given as a medicine in certain diseases, and in a book published in 1668 a few drops of sulphuric acid in water is recommended as a good drink for "Marines, Soldiers or for poor people, when Beer is scant and Malt dear."

All acids have further the important property that they neutralise alkalis and form salts. To make this clear we must consider what alkalis and salts are.

A typical alkali is caustic soda, more correctly called sodium hydroxide. It is usually supplied in white sticks, which have a soapy feeling.[1] If some sodium hydroxide is dissolved in water, the water has a soapy feeling too. If a drop of the solution is put on a slip of blue litmus the paper remains blue, but on a red litmus paper the alkaline drop produces a blue spot. An alkali turns red litmus blue, and an acid turns blue litmus red. There are many other substances besides litmus that go one colour with an acid, and another colour with an alkali. As they indicate to which class the stuff to be tested belongs they are called *indicators*. Two substances commonly used as indicators are methyl orange, which goes pink with acid and yellow with alkali, and phenolphthalein (a good word for a spelling competition—notice the "phth"), which is colourless with acid and crimson with alkali.

[1] Handle these sticks with great care, as they are very corrosive

All substances which have the soapy feeling and the right colour effect are called alkalis.

We have seen that acids produce one colour with litmus, alkalis another. Suppose we take in a little dish a solution of an alkali, say caustic potash (potassium hydroxide), and add sulphuric acid very slowly, stirring the liquid with a glass rod and testing it on slips of litmus. A point will come when it no longer turns the litmus blue, but faintly red. By adding now a drop or two of caustic potash and now of acid, as required, it will be found possible to get a liquid which has neither the alkali nor the acid effect; we say that it is *neutral*, and that the acid and the alkali have *neutralised* one another. This is a very important property.

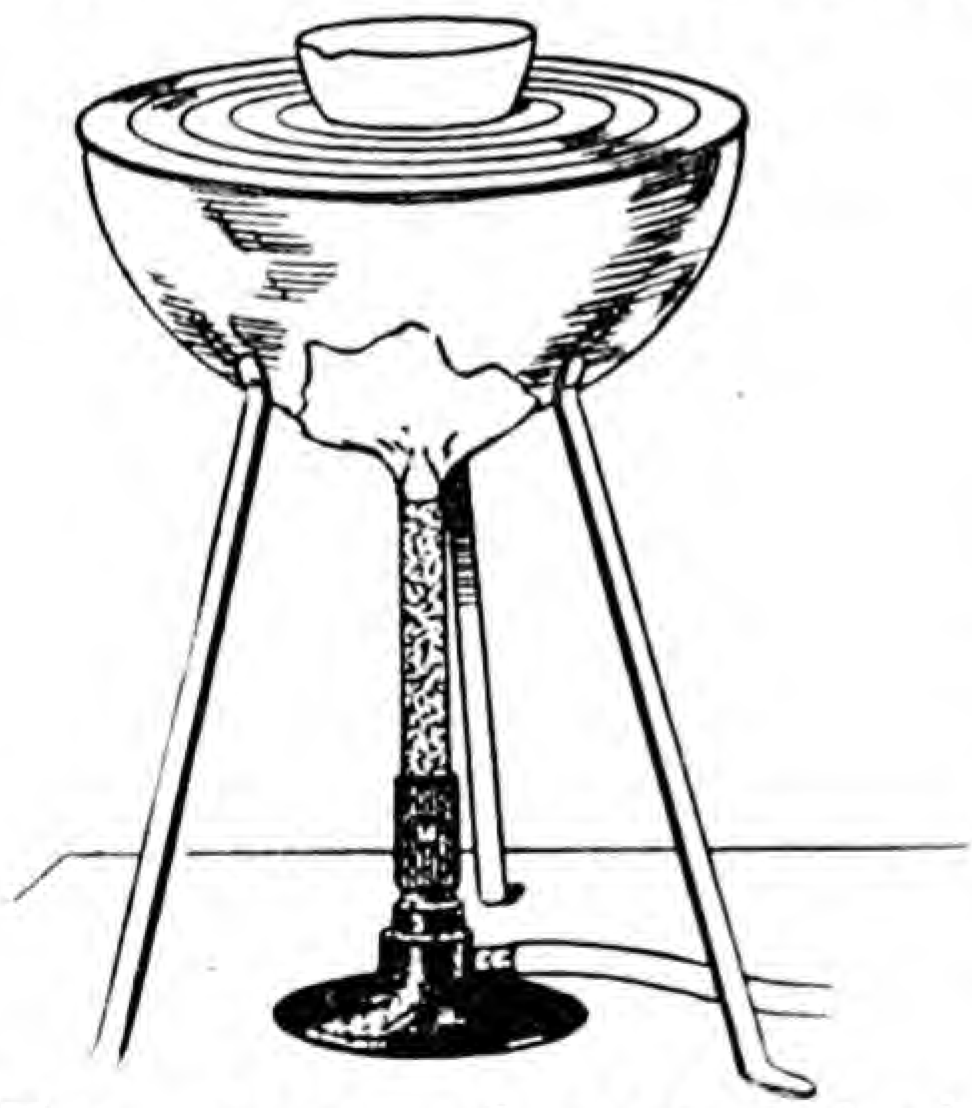


FIG. 120.—*A water bath. The flat rings can be taken out to make room for vessels of different size.*

Let us see what the result of the neutralisation is, by evaporating the solution. It is best to do this by putting the dish on a water bath, as shown in Fig. 120. with a flame underneath it. The steam produces a regular and not too violent heat. When all the water in the dish has evaporated away a white crystalline substance will be left behind. A tiny scrap may be tasted, and it will be found not to be acid. The potassium[1] in the caustic potash (which contains, besides

[1] The symbol for potassium is K, which stands for *kalium*, a mock Latin word made from alkali. The symbol for sodium is Na for *natrium*, a mock Latin word for natron, which is the name given to crude sodium carbonate.

the potassium, oxygen and hydrogen, and is written KOH) has taken the place of the hydrogen in the sulphuric acid, which is written H_2SO_4 (S for sulphur), and this hydrogen has formed water with the oxygen and hydrogen of the potash, which has boiled away with the other water. We are left with potassium sulphate, K_2SO_4. Such a substance, made from an acid by putting a metal (sometimes a substance that is not actually a metal, but behaves chemically just like a metal) in place of the hydrogen of the acid, is called a salt. Common kitchen salt is such a substance, for it can be made by putting sodium instead of the hydrogen in hydrochloric acid. Chemical salts do not in general taste salty, and there are hardly any properties which they all have in common. Some dissolve in water, others do not; some taste salt, others sweet, and so on. We call potassium sulphate, then, a salt of potassium, or a potassium salt. Enormous quantities of this substance are made as a fertiliser, which is just one example of the commercial uses of sulphuric acid.

The alkalis are composed of an alkali metal (that is, of sodium or potassium or one of certain other less common metals with similar properties, whose names need not trouble us) together with oxygen and hydrogen. Thus caustic soda, or sodium hydroxide, is NaOH, and potassium hydroxide is KOH. Certain of the compounds of other metals—such as calcium and zinc, say—with oxygen, and in some cases with both oxygen and hydrogen, act with acids in just the same way as alkalis do, yielding salts and water. Oxides and hydroxides[1] which behave like this are called bases, so that alkalis are just a

[1] The compounds with oxygen only are called oxides, those with OH are called hydroxides.

particular kind of base. We say, then, that bases act with acids to form salts and water. We can write

ACID + BASE = SALT + WATER.

It should be added that ordinary ammonia, which is a solution of the gas called ammonia (NH_3) in water, acts as a base, although it contains no metal. When neutralised by acids it forms ammonium salts. A pretty experiment is to put a little ammonia in a dish close to a dish containing hydrochloric acid. The vapour of the ammonia will combine with the vapour of the hydrochloric acid to form a white cloud, which consists of tiny crystals of an ammonium salt—that is, ammonium chloride, commonly called sal ammoniac. If you drop acids on your clothes you should quickly put ammonia on the place, for it will neutralise the acid, and not attack the cloth. Caustic soda would also neutralise the acid, but would itself eat a hole.

Salts can also be formed by the direct action of acids on metals. For instance, when sulphuric acid acts on zinc the zinc (Zn) takes the place of the hydrogen, and forms zinc sulphate, $ZnSO_4$, while the hydrogen is set free. If you slowly evaporate the liquid left after zinc has been dissolved in sulphuric acid to make hydrogen you will get white crystals of the salt, zinc sulphate.

A solution of carbon dioxide in water behaves as a weak acid, which will act upon a base dissolved in water, and form a salt called a carbonate. The solution of carbon dioxide is called carbonic acid, and at one time carbon dioxide was often called carbonic acid gas.[1]

When we bubble carbon dioxide through lime-water, which is a solution of the base calcium oxide (commonly

[1] This acid, of course, will not set free carbon dioxide from carbonates, as do the other acids which we have discussed.

called lime), the milkiness is due to little morsels of the salt, calcium carbonate, which is formed. When in our experiments we pass carbon dioxide over sodium hydroxide, which is a base, the salt sodium carbonate is formed.

Carbonates are very common salts. Sodium carbonate is found in nature in the soda lakes of Egypt and in the desert regions of Lake Magadi in East Africa. What is called washing soda is crystals of sodium carbonate. Calcium carbonate occurs in many forms in nature. Chalk is one form; coral is another; marble is another, in which the carbonate has been transformed by heat and great pressure into a mass of tiny crystals.

The Manufacture of Acids

The manufacture of sulphuric acid is an extremely important industry. The acid is so widely required that over a million tons are made every year in each of the countries, Great Britain, Germany and the United States of America. Nearly half of this enormous quantity is used for making fertiliser of different kinds, and a very large quantity is needed in the process of refining the crude petroleum that comes out of the earth. It is used in galvanising, in making explosives, and in a thousand other ways. A rough idea of the quantities required for the chief purposes is given by Fig. 121.

When sulphur is burnt in air it combines with the oxygen to form a choking gas called sulphur dioxide, SO_2. There is, however, another compound of sulphur and oxygen, called sulphur trioxide, SO_3, which contains more oxygen, three parts of oxygen to the amount of sulphur that combines with two parts of oxygen in sulphur dioxide. This is a good example of the law of multiple

proportions. Sulphur trioxide dissolved in water makes sulphuric acid. In the large works set up to make sulphuric acid the sulphur dioxide is produced by burning not sulphur itself, but pyrites, which is a very common compound of iron and sulphur. The extra oxygen and the water are added by a rather difficult chemical process which need not trouble us here.

Hydrochloric acid is a compound of hydrogen with a gas called chlorine[1] dissolved in water. The hydrogen

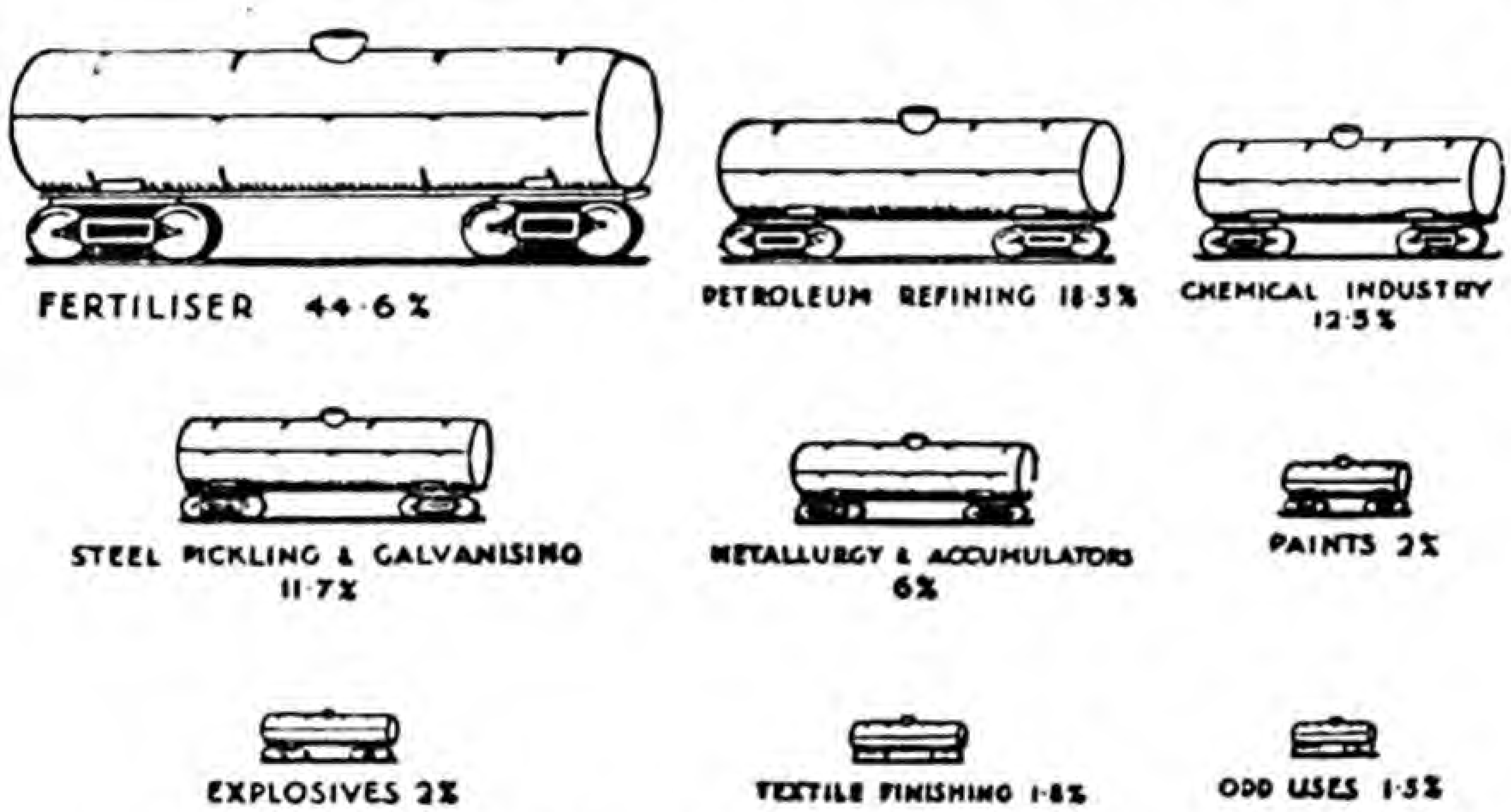


FIG. 121.—*The chief uses of sulphuric acid.*
(*Adapted by permission from Partington's "Everyday Chemistry."*)

and chlorine combine to form a gas called hydrogen chloride. We can make it in the laboratory by the action of sulphuric acid on ordinary cooking salt, which is sodium combined with chlorine, or sodium chloride, as it is called. It is written NaCl, the Cl standing for chlorine and the Na for sodium.[2] The salt is placed in a flask, and the acid poured in through the thistle funnel, as shown in Fig. 122. A gas comes off which is heavier than air, and can be collected by downward displacement. This gas is the hydrogen chloride. The sodium in the ordinary

[1] See p. 187.

[2] See footnote to p. 180.

salt takes the place of the hydrogen in the acid, and sodium sulphate is formed. The hydrogen combines with the chlorine in the ordinary salt, forming the gas HCl that is given off.

Hydrogen chloride is intensely soluble in water, and must not be bubbled direct into water, for, if this is done, the liquid absorbs the gas so strongly that it rushes back into the flask, and an explosion may result. The readiness with which it dissolves may be prettily and safely shown

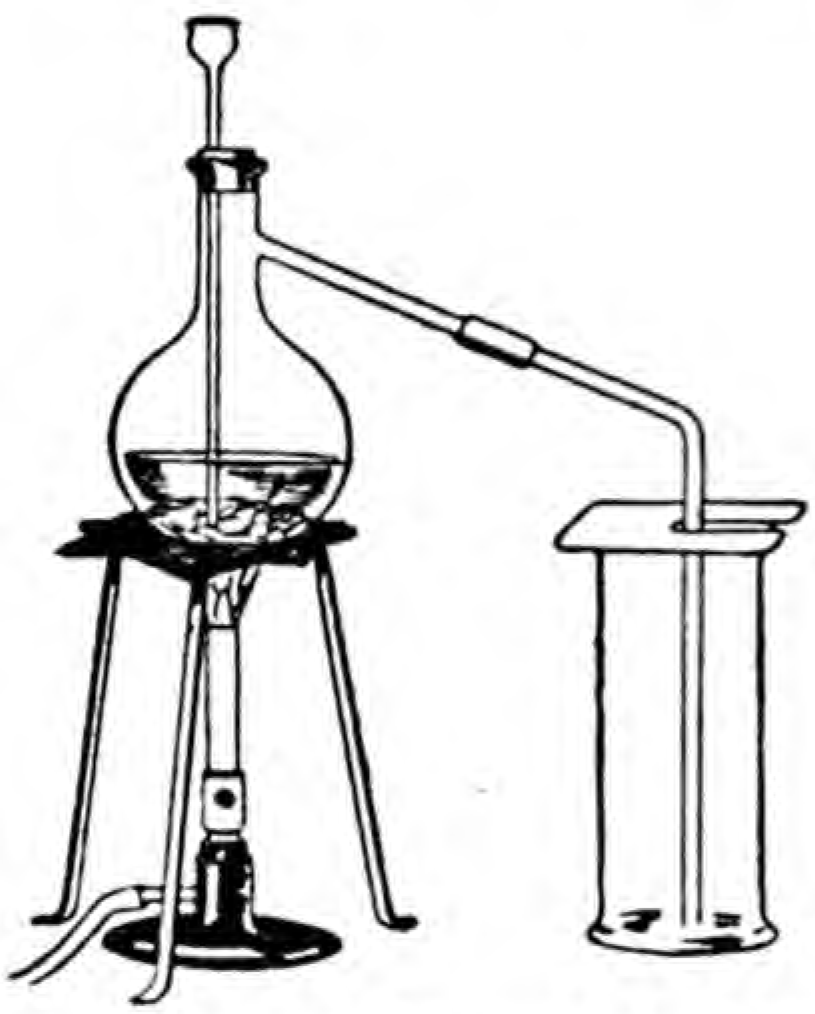


FIG. 122.—*Making hydrochloric acid.*

FIG. 123.—*The hydrochloric acid fountain.*

as follows. A flask is filled with HCl by downward displacement, as shown in Fig. 122, and is then quickly closed with a cork provided with a long tube. The flask is then turned upside down, with the end of the tube under water.[1] The gas at once begins to dissolve and the water rises. As soon as a few drops enter the flask they absorb the gas more quickly, and the water rises so rapidly to take its place that a pretty fountain is formed.

[1] The tube should be closed with a piece of rubber tube and a pinchcock, which can be opened under water.

If the water in the dish is made blue with litmus the fountain will be red, owing to the hydrochloric acid formed in the flask.

Large quantities of commercial hydrochloric acid, often called spirits of salt, are used for cleaning the surface of iron sheets before they are tinned for making ordinary "tins," or covered with zinc (galvanised, as it is called) to make corrugated iron.

Nitric acid is made by the action of sulphuric acid on potassium nitrate or sodium nitrate, commonly called nitre or saltpetre.[1] Potassium nitrate is found in the soil in certain parts of the world, especially in India, while sodium nitrate is plentiful in the deserts of Chile, Peru and Bolivia. The experiment is done in a retort as the acid fumes would attack the cork if it were done in an ordinary flask.

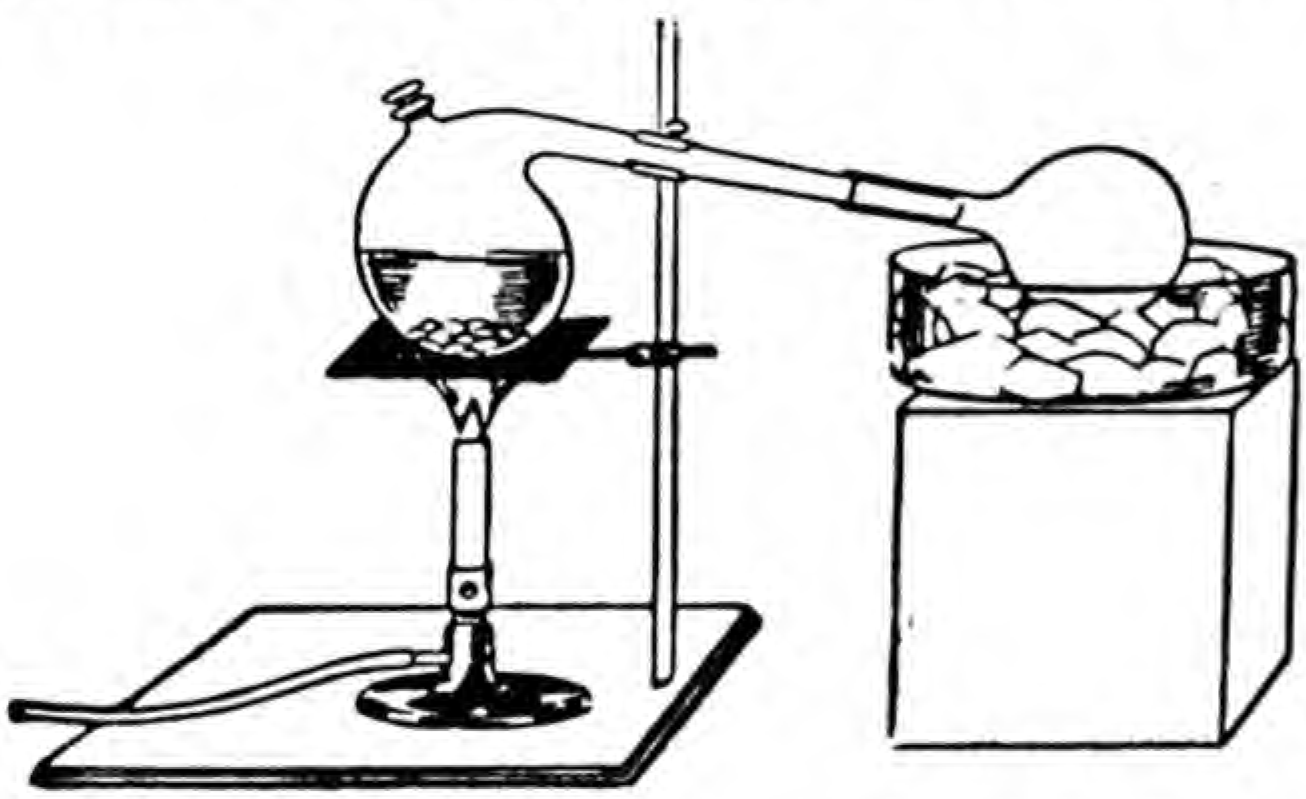


FIG 124.—*Making nitric acid.*

The acid comes off as vapour, and can be collected in a flask cooled by being supported on ice, as shown in Fig. 124. Commercially it can be made in this way, or by causing the nitrogen of the air to combine with the oxygen by means of the electric arc. At the high temperature of the arc the two gases, which ordinarily do not act on one another, give a chemical compound which, on cooling, becomes nitrogen peroxide, NO_2. Dissolved in water this becomes nitric acid, HNO_3. Much nitric acid is made from the atmosphere in this

[1] Sodium nitrate is called Chile nitre or Chile saltpetre, to distinguish it from the potassium nitrate.

way in Norway, where electric power is very cheap, since the dynamos can then be driven by water power. Very large quantities of nitric acid are employed to make calcium nitrate, which is used as a fertiliser, often called an artificial manure. The sodium nitrate found in the dry districts of Chile is also used for the same purpose.

In speaking of hydrochloric acid and of common salt we have mentioned the gas chlorine, which is a very important element. It can be prepared by placing manganese dioxide, composed of the elements manganese and oxygen, in a flask with strong hydrochloric acid, and warming it. The manganese takes the place of the hydrogen in the acid, which forms water with the oxygen of the dioxide: some of the chlorine is set free, and the rest combines with the manganese to form manganese chloride. The apparatus is best arranged as shown in Fig. 125, so that the gas bubbles through water, which removes certain impurities, and it may be collected in an open glass cylinder by downward displacement, since it is more than twice as heavy as air. It is yellowish green in colour, which is why it is called chlorine, for *chloros* is Greek for this colour.

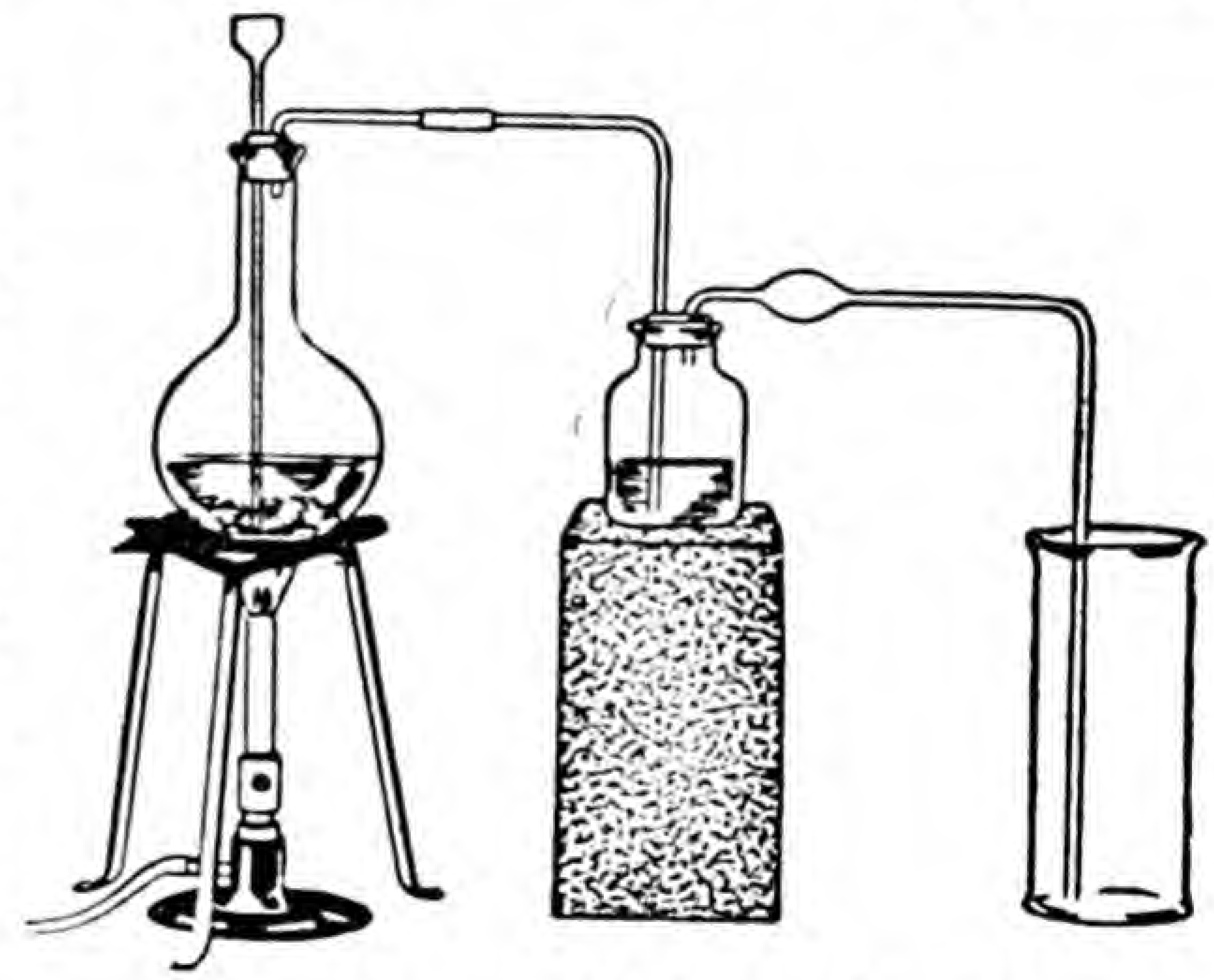


FIG. 125.—*Making chlorine.*

The very irritating smell of chlorine will be noticed at once by anyone who prepares it. Care should be taken not to breathe it in any quantity: in fact it was the first substance to be used as poison gas by the Germans in the

Great War. Steel cylinders of compressed chlorine were brought into the trenches early in 1915, and opened when the wind was blowing from the German lines towards the British.

Chlorine combines violently with a great number of elements, forming compounds which are called chlorides. They are the same compounds as can be prepared by the action of hydrochloric acid on bases—they are salts. A very interesting experiment is to cut a piece of the soft metal sodium,[1] put it in a hard glass tube, and pass chlorine over it, as shown in Fig. 126. The sodium will catch fire, and burn with a very bright flame. This shows that burning can take place without oxygen, for there is nothing there but sodium and chlorine. When all the sodium has burnt, a white powder looking something like common salt will be found in its place. Taste it: it *is* common salt. Salt, as we have said, is a compound of sodium and chlorine, and nothing else. This experiment proves it, and gives a very good example of the way in which a chemical compound has quite different properties from those of the elements which make it up. If sodium were put into the mouth it would combine violently

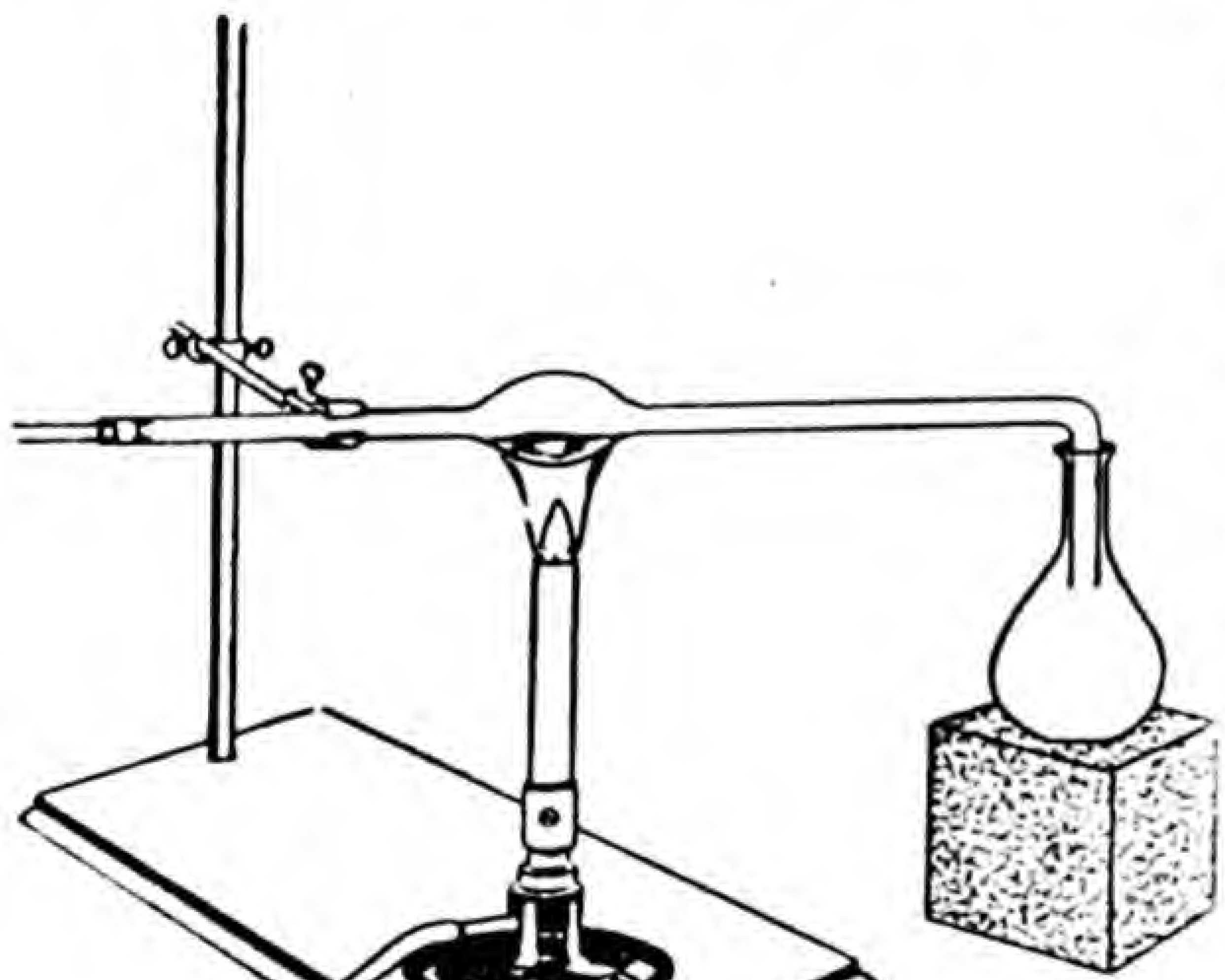


FIG. 126.—*Burning sodium in chlorine.*

[1] The sodium, which, as has been said, should be kept under oil, must on no account be brought into contact with water, or it will catch fire, and an explosion may result. See p. 190.

with the water there, getting very hot and making a horrible burn. Chlorine would choke you. But sodium chloride is one of the necessities of life.

Pure Metals and Alloys

One of the most important branches of practical chemistry is concerned with the obtaining of metals from their ores. We have already spoken of how aluminium is obtained by *electrolysis*, which is the scientific word for passing an electric current through a liquid and causing a chemical change. The mineral, bauxite, which contains

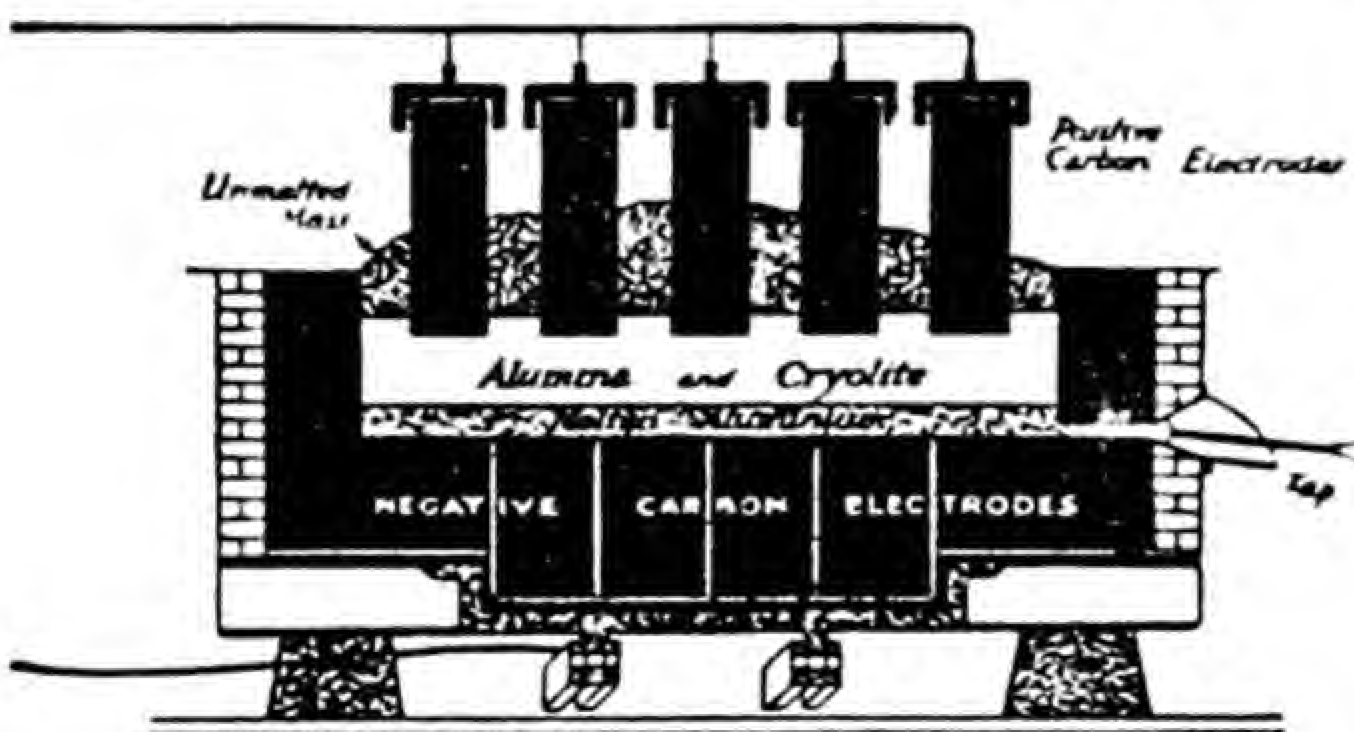


Fig. 127.—*How aluminium is prepared from a kind of clay by electricity.*

the aluminium to be won, is dissolved not in water, but in melted cryolite, which is a mineral containing both aluminium and sodium. The mixture is contained in an iron box lined with carbon, which is fastened to the positive side of the electric circuit, while carbon rods, which are fastened to the negative side, dip into it. Only about 6 volts difference of potential is needed. The heating effect of the current keeps the minerals molten. The aluminium which is set free sinks to the bottom of the bath.

The use of electrolysis in winning metals from ores

is increasing as electricity becomes cheaper. This method of preparing zinc is being more and more used in America and Australia; although it costs a little more than other ways it has the great advantage that the zinc is purer. This advantage of purity belongs to the electrolytic method, which is, for instance, used for getting very pure copper (called "electrolytic copper") from ordinary rough copper. The method is also used for preparing the metal sodium, which we have already met, and the similar soft metal potassium, from sodium hydroxide and potassium hydroxide respectively. These metals were first discovered by Sir Humphry Davy in the year 1807, by means of electrolysis. He placed a small piece of caustic potash on a platinum plate, connected to the negative pole of a battery, and brought a platinum wire, connected to the other pole, in contact with the potash. At the negative surface "small globules having a high metallic lustre, and being exactly similar in visible characters to quicksilver, appeared, some of which burnt with explosion and bright flame, as soon as they were formed, and others remained, and were merely tarnished, and finally covered by a white film which formed on their surfaces." The globules were metallic potassium, which at once acts on any moisture present. If there is enough moisture the heat developed by the action may be so strong that the potassium bursts into flame: otherwise it acts less violently with the moisture, taking up hydrogen and oxygen, and forming white potash again. The preparation of metallic sodium was carried out in the same way.

In spite of its increasing use, electrolysis is responsible for very little of the metals we see around us, and has only been mentioned first because we had spoken of the method in an earlier chapter. Let us turn to some of the

chief metals, and first of all, iron and steel. These metals are needed in immense quantities, and at a small price, so that the costs of production have to be kept very low, and the processes carried out on a very large scale.

The commonest iron ores consist of iron combined with oxygen. The ore called hæmatite is red iron oxide, which is written Fe_2O_3, as already mentioned, and contains 70 per cent. of iron. It is commercially the most important. It is found in England, as, for instance, in the district north of Barrow-in-Furness. Limonite is the same oxide combined with water, and is called hydrated iron oxide: it is brown. It is not, of course, just wet hæmatite, for the water is chemically built into it, as it is in copper sulphate crystals. Magnetite is a different oxide, slightly richer in iron, and is written Fe_3O_4. It is black, and, as we have said in Chapter III, is sometimes magnetic, but not always. It is not very common in England, but occurs in Scandinavia, and, with the other iron ores, in the enormous deposits near Lake Superior in North America. The Mesabi district, or range, as it is called, in those parts has produced over 40 million tons of ore in a year. There is also a common iron ore which is a carbonate; that is, it contains carbon as well as oxygen, and is written $FeCO_3$. It is called siderite, and is often found, mixed with clay, as what is called clay ironstone.

The pyrites, which we have already mentioned, is not used for making iron, as it is hard to get rid of all the sulphur, and a little sulphur is very objectionable as an impurity in iron, for it makes it brittle.

To prepare iron from the common ores, therefore, we need something that will take away the oxygen. The cheapest thing that will do this is the element carbon.

used in the form of coke. Taking away the oxygen of a compound is called *reducing* it in chemistry, so that we can say the iron oxides are reduced in a blast furnace, of which Fig. 128 is a picture showing it cut across. It is made of steel plates lined with fire brick. At the bottom is a circle of pipes called twyers,[1] through which hot air can be blown. The top is closed with a cone, point upwards: when this is lowered any stuff placed above it falls at once into the furnace. The furnace is charged through the top with roasted iron ore, coke and limestone. This limestone combines with the stony part of the ore, which does not itself contain any iron, and forms a waste substance which is called slag. This slag is liquid at the temperature of the furnace, and trickles down to the bottom, where it is run off through a hole. When it cools it forms a kind of very coarse glass, which was formerly considered useless. Nowadays some of the slag is used for road making, and for making cement. Near blast furnaces there are great hills of this product, called slag heaps. They represent the unwanted part of the ore; the limestone which makes it run is called a *flux*.

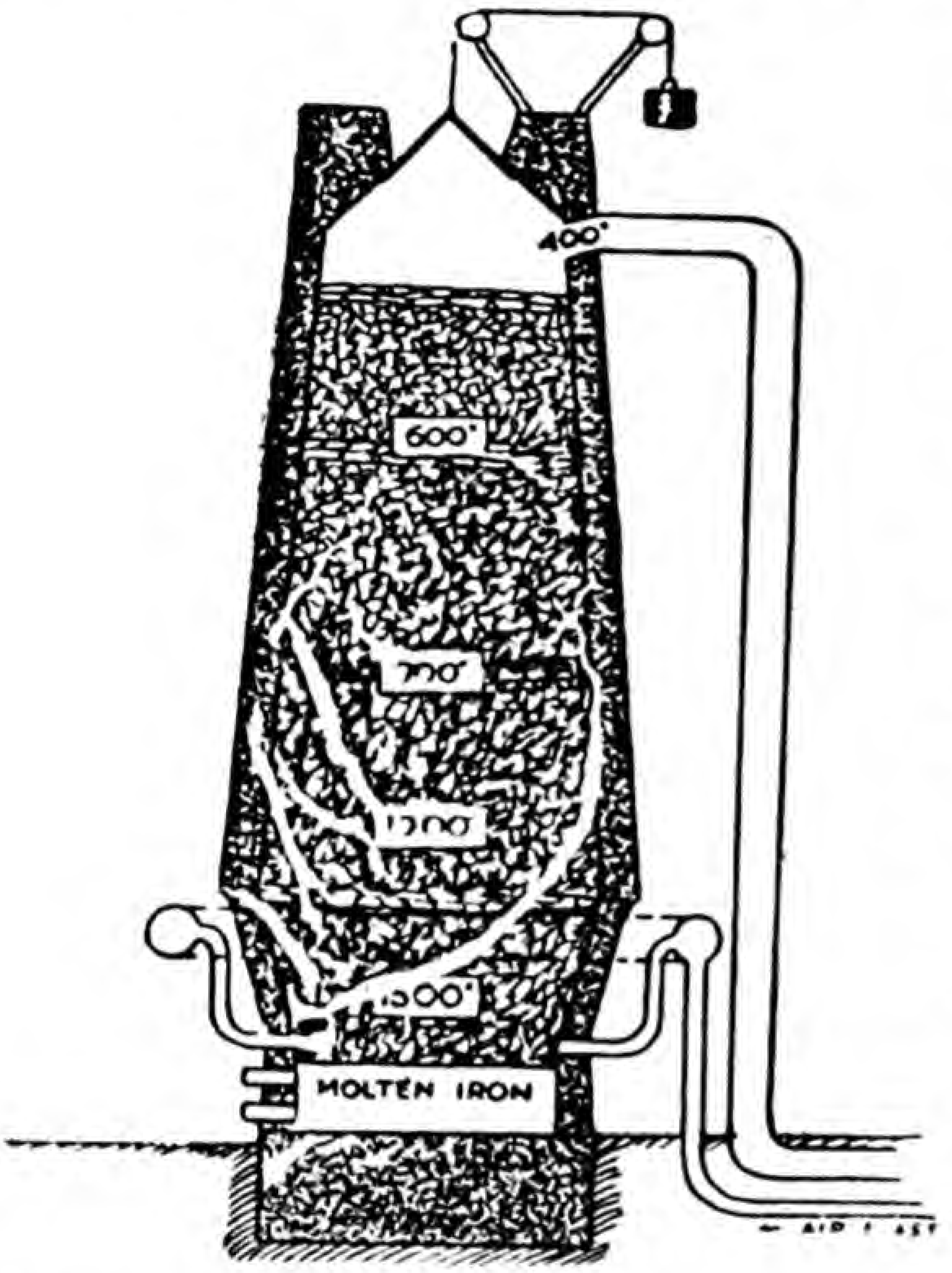


FIG. 128.—*A blast furnace for making iron, shown cut across.*

[1] The French word *tuyères* is often used in English for twyers, and is the origin of the English word.

The blast of air through the blast furnace converts the carbon at the bottom of the furnace to carbon monoxide; this gas then burns and heats the furnace, taking up oxygen from the ore, and becoming carbon dioxide. The general effect of the chemical changes that go on is that the carbon in the furnace takes up the oxygen from the ore, and hot carbon dioxide mixed with carbon monoxide (and with the nitrogen left from the air) passes out at the top. The molten iron trickles down and is run off from a hole at the bottom of the furnace. The melted slag floats on top of it, and can be run off separately. There is enough carbon monoxide in the gases from the top of the furnace to burn, and in the old days the furnaces could be seen flaring when they were in blast, but today heat is not generally wasted like this. The gases are collected and used to heat the air that is blown into the furnace, so that it enters all ready warmed up.

This is the way that pig iron is made. The ores of many other metals are likewise treated with carbon to reduce them: if the ores are not themselves oxides they have to be roasted first to convert them into oxides. With zinc, for instance, besides oxide ores we have zinc carbonate and zinc sulphide ores, which are treated in this way. When the zinc oxide is reduced by heating with carbon the zinc distils over in the form of vapour, just as water distils over in the form of steam, and condenses in special vessels as zinc metal. Copper oxide and copper carbonate ores are treated much as the corresponding zinc ores are, except that the copper does not distil over, but remains with the carbon. Lead can be prepared from the ore galena, which is lead sulphide, by roasting in two stages: in the end the oxygen of the

air unites with the sulphur to form sulphur dioxide, SO_2, and the lead is left. The chief tin ore is *cassiterite*, which is tin combined with oxygen, or tin dioxide. This also is reduced by heating with carbon. It will be seen, therefore, how important in winning metals from their ores is the simple process of reduction by carbon.

Let us return to our pig iron. The iron is not of wide use in this state, but is mostly converted into wrought iron or steel. Wrought iron, which is iron containing only a small amount of impurity, is also called malleable iron, the word meaning that it can be hammered into shape, unlike pig iron, which is brittle, and breaks if struck with a heavy hammer. Things like iron stoves and iron drain-dipes are made of pig iron, which is generally called cast iron. Wrought iron is very tough, and is used for chain cables and sheet iron, among other things. Formerly it was in wide demand, but nowadays steel has largely replaced it. Wrought iron is made by strongly heating pig iron in a furnace: the impurities are combined with oxygen and rise to the top, as a kind of slag, and are then removed. We must now say a word about steel, what it is and how it is made.

Common steel is iron combined with a small quantity of carbon. The carbon is not in little bits in it, like tiny currants in a pudding, as it is in pig iron, but more thoroughly mixed and joined up to the iron, running all through the substance. The actual scientific difference between iron and steel is too long a story for us here. The structure of all alloys, and especially steel, is very complicated. One of the ways of studying it is by polishing a surface of the metal, treating it with a little acid, which attacks different parts of the structure differently and

so shows them up, and then examining with a microscope.[1] Single metals can be shown in this way to be all composed of little metal crystals fitted together, as shown in Fig. 129*a*, which is a picture of a surface of lead, magnified 70 times. Alloys, however, may have all kinds of appearance,

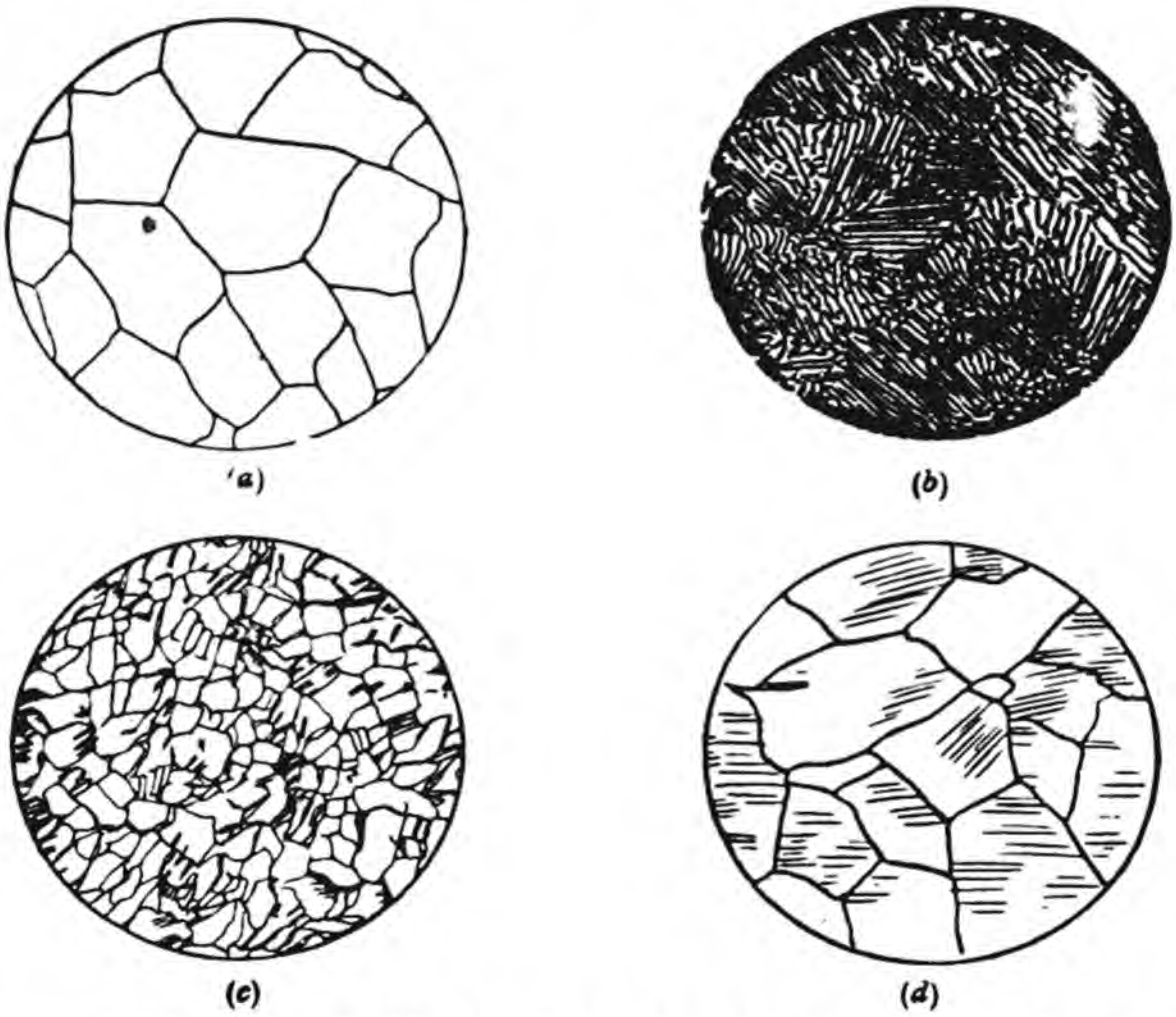


FIG. 129.—*Microphotographs of metals.* (*a*) *Lead*, × 70 (*b*); *cast iron*, × 500; (*c*) *manganese steel as cast*, × 25; (*d*) *same manganese steel after toughening by plunging the hot material into cold water*, × 25. ("× 100" *means* "*magnified to* 100 *times the size across*.")

according to the proportions of the different metals in them, and the way they have been treated or cooled. Steels in particular have very varied structures, and from the microscopic pictures, or microphotographs, as they

[1] There are other methods of examining the structure of metals and alloys, of which the use of X-rays is the latest.

are called, the man of science can tell you a great deal about the steel, and what it will do. Great improvements in steels have been made with the help of such pictures. Fig. 129 shows some microphotographs of different metals. Notice particularly the great difference in structure which is produced in the manganese steel by tempering, as the process of heating and then suddenly cooling is called. Special steels which contain other metals besides iron are mentioned a little later on.

Cast (pig) iron from the blast furnace contains 3 or 4 per cent. of carbon. Most modern steel is made by burning out part of this carbon. This is done either by the process invented by Bessemer, and named after him, or by the open-hearth process invented by Siemens and Martin.

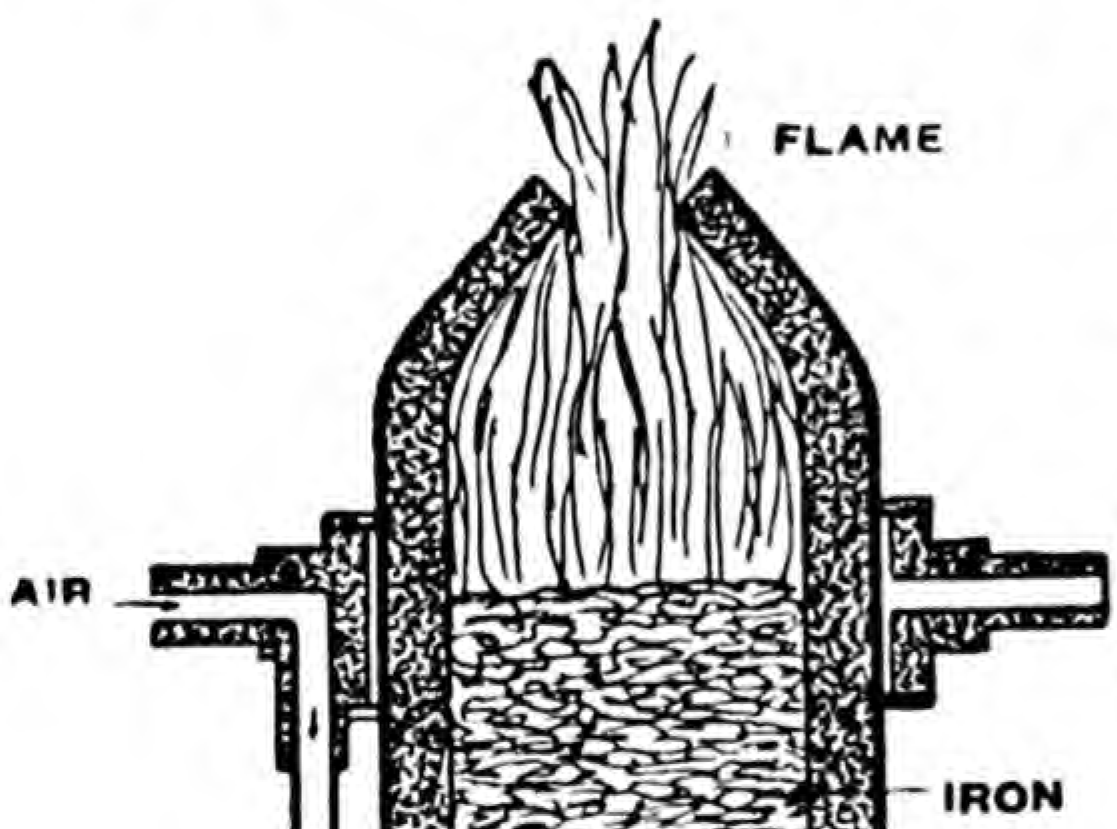


FIG. 130.—*A section of a Bessemer converter.*

In the Bessemer process all the carbon and some other impurities are burnt out by blowing air through the melted iron, and afterwards just the amount of carbon required in the steel is added. Fig. 130 shows a section through a Bessemer converter, from which it will be seen where the air is forced in. When the blowing takes place the carbon monoxide formed burns at the mouth of the converter in a great flame, as shown in Fig. 131. The converter is then tilted to pour off the slag, and the right quantity of what is called Spiegeleisen,[1] which

[1] From the German word for it. *Spiegel* means mirror, and *Eisen* is iron, and the name is derived from the bright reflections which it gives.

is iron containing carbon and also manganese, is added. The liquid steel is later poured out by further tilting the converter.

In the open-hearth process the molten cast iron from the blast furnace is run into a large flat pan, or hearth, and kept molten. A cheap form of gas, called producer

FIG. 131.—*A Bessemer converter during the blowing.*

gas, which contains a lot of carbon monoxide, is used to provide the heat. Some hæmatite is then added, and the oxygen in it burns with part of the carbon, which is thus taken out, and steel left. In this process, by choosing the amount of hæmatite, just as much carbon can be removed as is wished. The open-hearth process takes 10

hours or so, whereas the blowing of a Bessemer converter takes only about 7 minutes, but much more steel is made at one go in the open hearth. Typical steels contain about 1 per cent. of carbon.

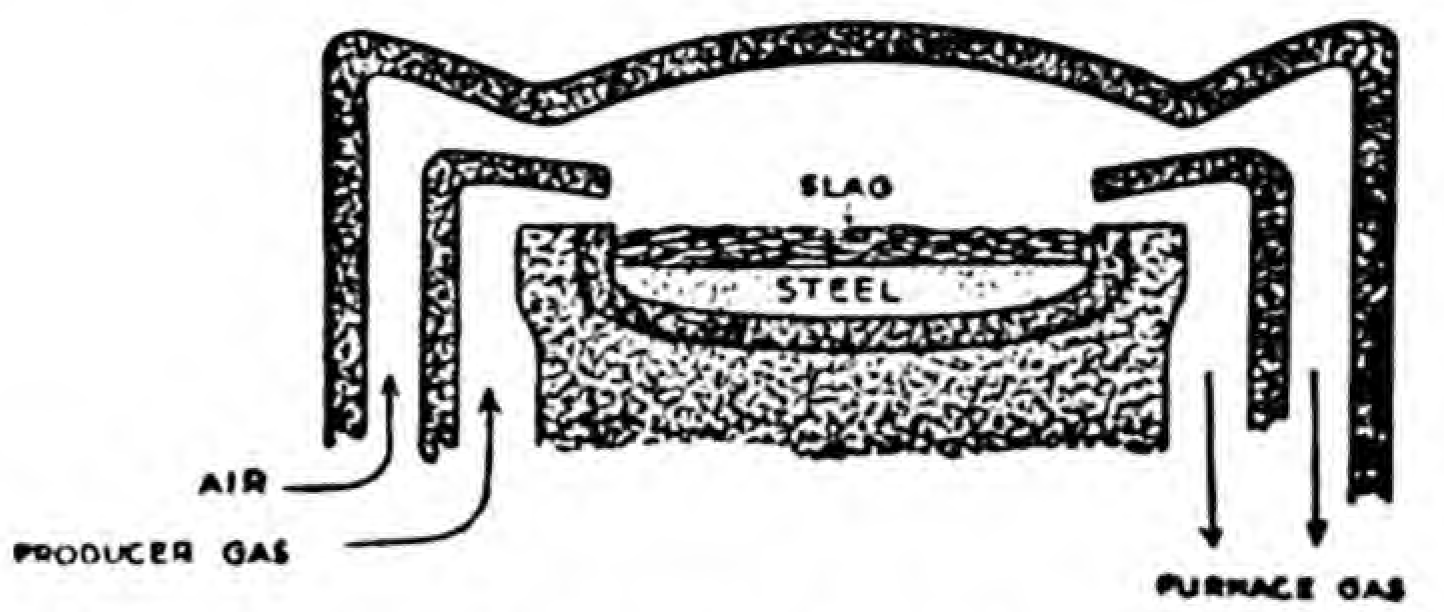


FIG. 132.—*The open hearth process for making steel.*

All kinds of special steels can be made by adding small quantities of other metals. Manganese, chromium, titanium, tungsten, molybdenum, vanadium, and nickel are the names of some that are used. Stainless steel, for instance, as used for table-knives, which does not rust or stain with lemon-juice, is iron with 12 per cent. of chromium and a little carbon. Nickel steels are very tough and used for armour plate for battleships. Special tool steels, for cutting metals at high speed, are made by adding tungsten, chromium and other metals to the iron. They cut even when red hot with the friction, whereas an ordinary steel would lose its edge at once at such a temperature. Manganese steel, of which microphotographs are shown in Fig. 129, stands up to wear extremely well, and is used for such things as tramway points, where severe rubbing and banging is expected. It was also used for making the helmets, or "tin hats," in the war. There are dozens of other kinds of steel for special purposes. In a modern locomotive, for instance, 32 different kinds of steel are used, each with its special properties, and, we may add, 12 different kinds of brass and bronze, which are also alloys.

Steel is the most important alloy for our present

civilisation; in fact, we may call this the Age of Steel. Something like 80,000,000 tons of steel are produced in one year, whereas before the Bessemer process, first put forward in 1856, only 4,500,000 tons of cast iron and no steel were made. There are very many alloys of other metals which are of the greatest use. Brass is made of copper and zinc. Bronzes are made of copper with other metals added, chiefly tin: the kind used for making pennies is 95 per cent. copper, 4 per cent. tin and 1 per cent. zinc. A very tough and light alloy, of the utmost importance for aeroplanes, is called duralumin: it is made of aluminium with 4 per cent. copper, 1 per cent. manganese and 1 per cent. magnesium added. Weight for weight (not size for size) duralumin is much tougher than steel.

A very amusing alloy is made of 50 parts of bismuth, 25 parts of lead, 12½ of tin and 12½ of cadmium: it is called Wood's metal. The queer property is that it melts at only 70° C., far below the boiling point of water. If a teaspoon made of this alloy is put into very hot tea the end simply melts away, much to the surprise of the stirrer, since it looks much like an ordinary spoon, the metal being white and something like silver in appearance. These easily fusible alloys have a more important use than this, for they can be used for fire sprinklers, which act of themselves if there is a fire. The ends of pipes leading from a tank containing water, or some special extinguishing liquid, to the place where fire is considered likely are stopped with plugs of fusible metal: if a fire starts the metal soon melts, and the water pours out and extinguishes the burning.

Ordinary alloys are not chemical compounds, for we can alter the composition as we like, putting a little more or a little less of one metal or the other. Neither are

they mixtures, for we cannot separate out the parts except by chemical action. Many of them are rather more like a solution of one metal in another, for we know that we can, for instance, dissolve sugar in water in all kinds of different proportions. In other alloys little crystals of different composition lie side by side. As we have said before, this is a very difficult part of our subject, and we cannot say much about it here, but you should know how interesting the study of alloys is. As a result of the scientific methods of examining their structure it is no longer so common for people to try to discover good alloys by just throwing different metals into a melting pot, and hoping for the best.

Glass is a substance made of things that, when melted, dissolve in one another in proportions that we can alter as we like, within reason. Its structure is very complicated, but at any rate we can say that it is not a definite chemical compound, like salt or sugar. Ordinary glass is made of sand, soda ash (sodium carbonate) and limestone, melted together. Glass does not have a definite temperature at which it becomes solid, as metals and alloys do. If you heat a piece of glass it becomes softer and softer, as butter does when heated, and you cannot say at one moment "It is solid" and a little later, "Now it is liquid." At a certain temperature it becomes like dough, at a higher temperature like treacle, and finally, if heated enough, nearly as runny as water. It is thanks to this property that we can blow glass. In hand work the glass blower takes a lump of molten glass, at the right temperature, on the end of a hollow iron rod, and then blows. He gets a round bulb which is still soft, and with very simple tools he can push it into the shape he wants. To make a cheap bottle a mould may be used. This is

fastened round the blob of glass on the end of the blow-pipe, and the glass is then blown out until it fits the

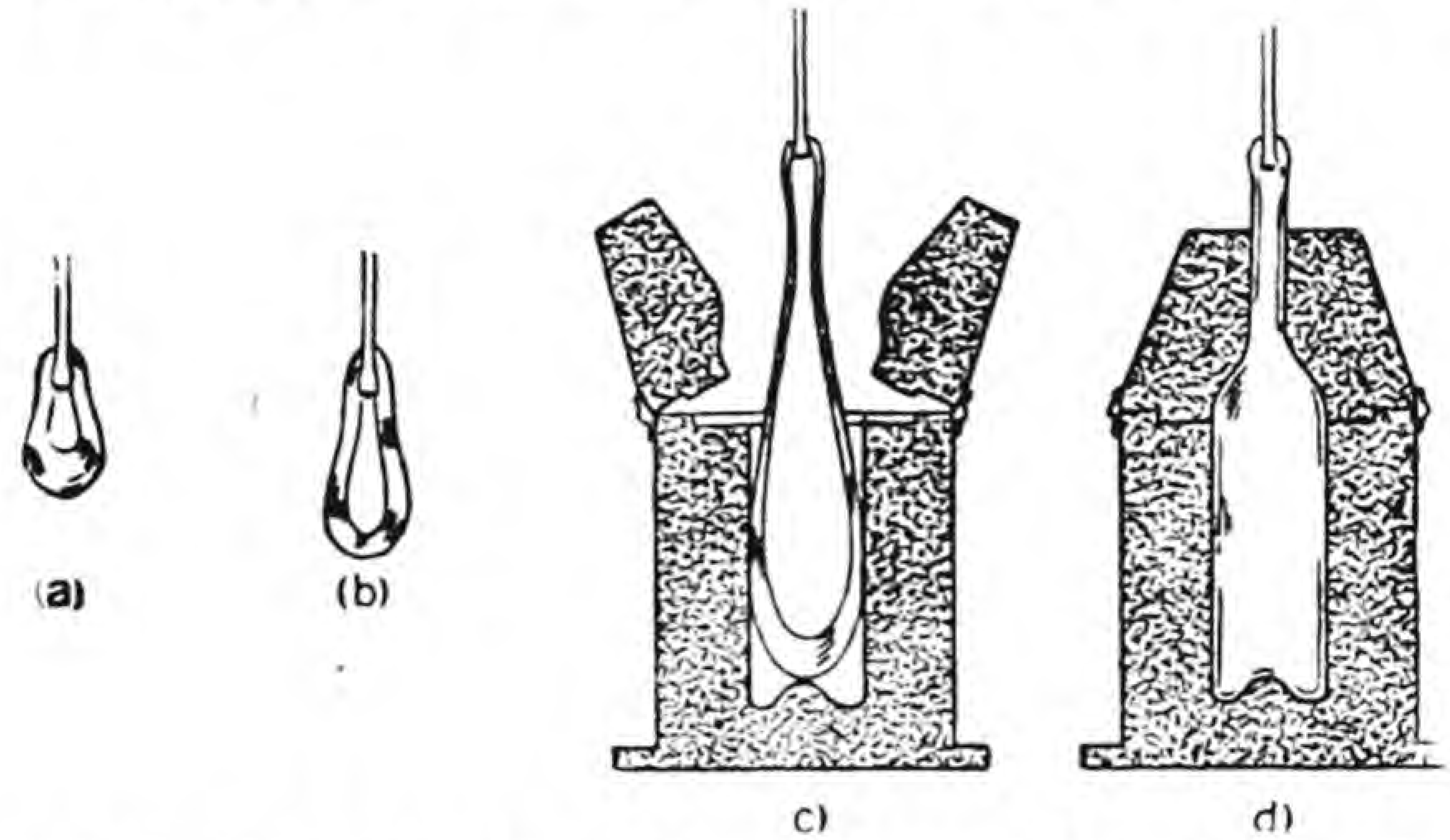


Fig. 133.—*Blowing a bottle. A blob of glass is first blown out into a long hollow bulb, as shown in (a) and (b). The bulb is then put in a mould, as shown in (c), and the mould closed. The glass is then again blown so that it takes the exact shape of the mould (d).*

mould. Fig. 133 makes clear how the mould is used in making a bottle. To shape the neck a special tool,

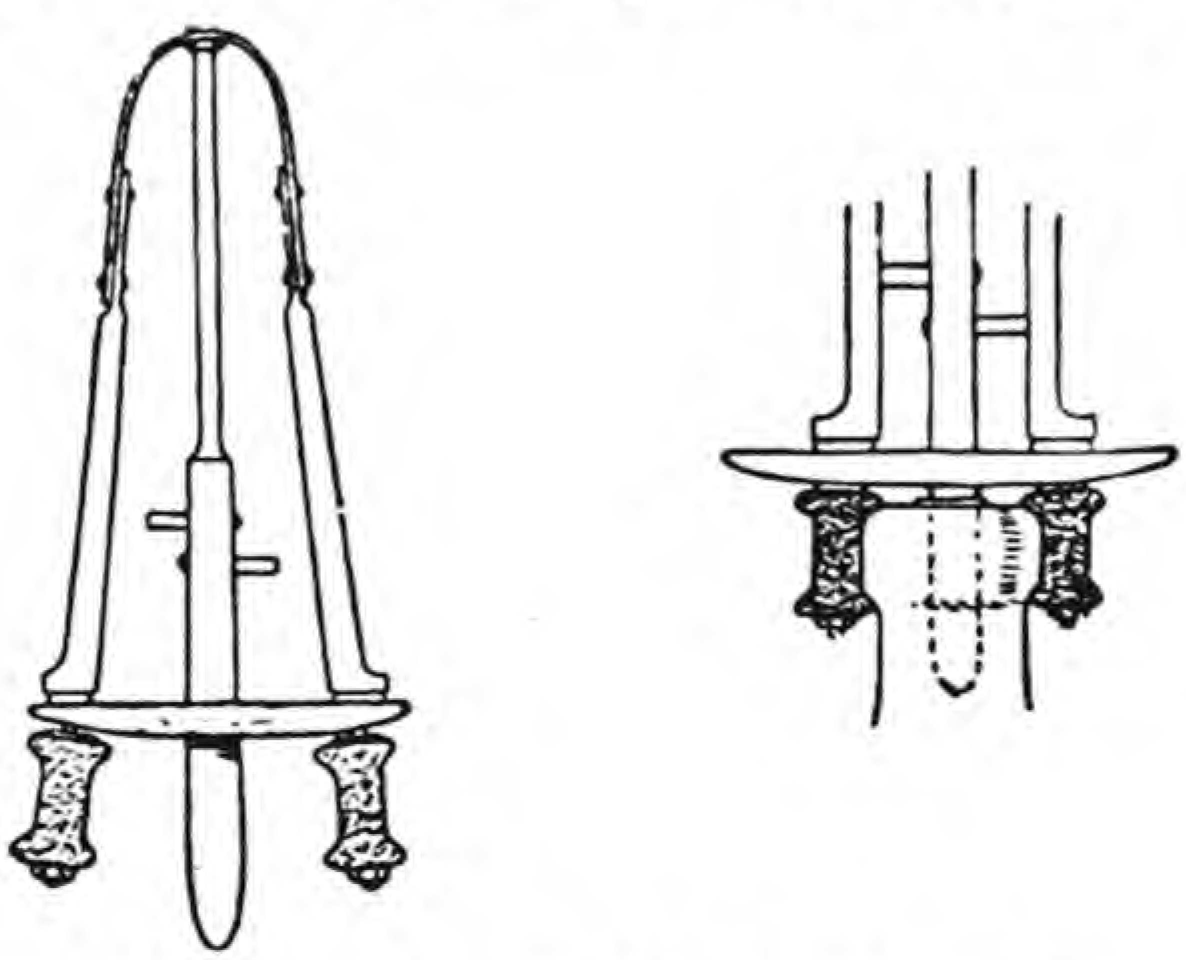


Fig. 134.—*How a bottle neck is formed.*

shown in Fig. 134, is employed. The blunt spike is put into the opening at the top of the bottle, and the edge is

then gripped and shaped by the little wheels, which are turned round. All this time the glass is in a softish state, like dough.

Bottles are now made by machinery, but the principle is the same. A certain amount is first sucked up from a large vessel full of glass in a melted state. This short rod of glass is then shut round with a mould, and air is

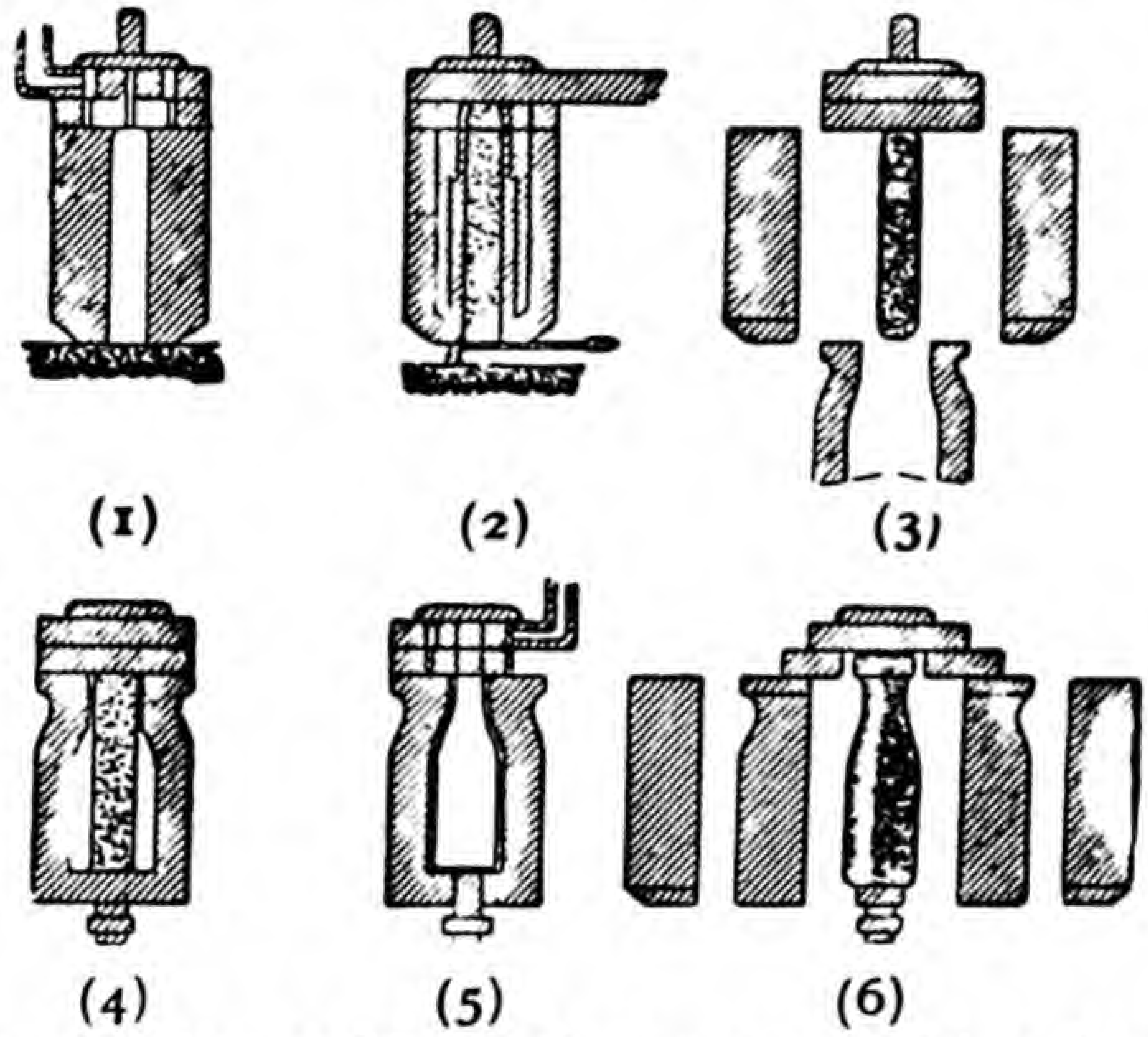


FIG. 135.—*Glass bottle machine. An empty mould is brought just above the molten glass,* (1), *and a rod of glass is sucked into it,* (2). *This mould then goes away, and its place is taken by another mould, the shape of a bottle,* (3) *and* (4). *The glass is blown out to fit this mould,* (5). *The mould then moves away,* (6).

blown into it, so that it becomes hollow and takes the shape of the mould (Fig. 135). All the processes are carried out automatically by the machine. Such a machine, served by six men, can easily make 1,200 bottles in an hour.

Just as there are dozens of kinds of steels, there are dozens of kinds of glasses for special purposes. Window glass, bottle glass and the glass for making tubing for

the laboratory, are all different, and for use in optical instruments, such as telescopes, there are whole series of special glasses. There are glasses to stand special high temperature, and there are coloured glasses. One of the most remarkable glasses is made of melted quartz crystals. It is expensive, because a very high temperature is needed to melt the quartz. The property of this glass is that it will stand sudden changes of temperature: it

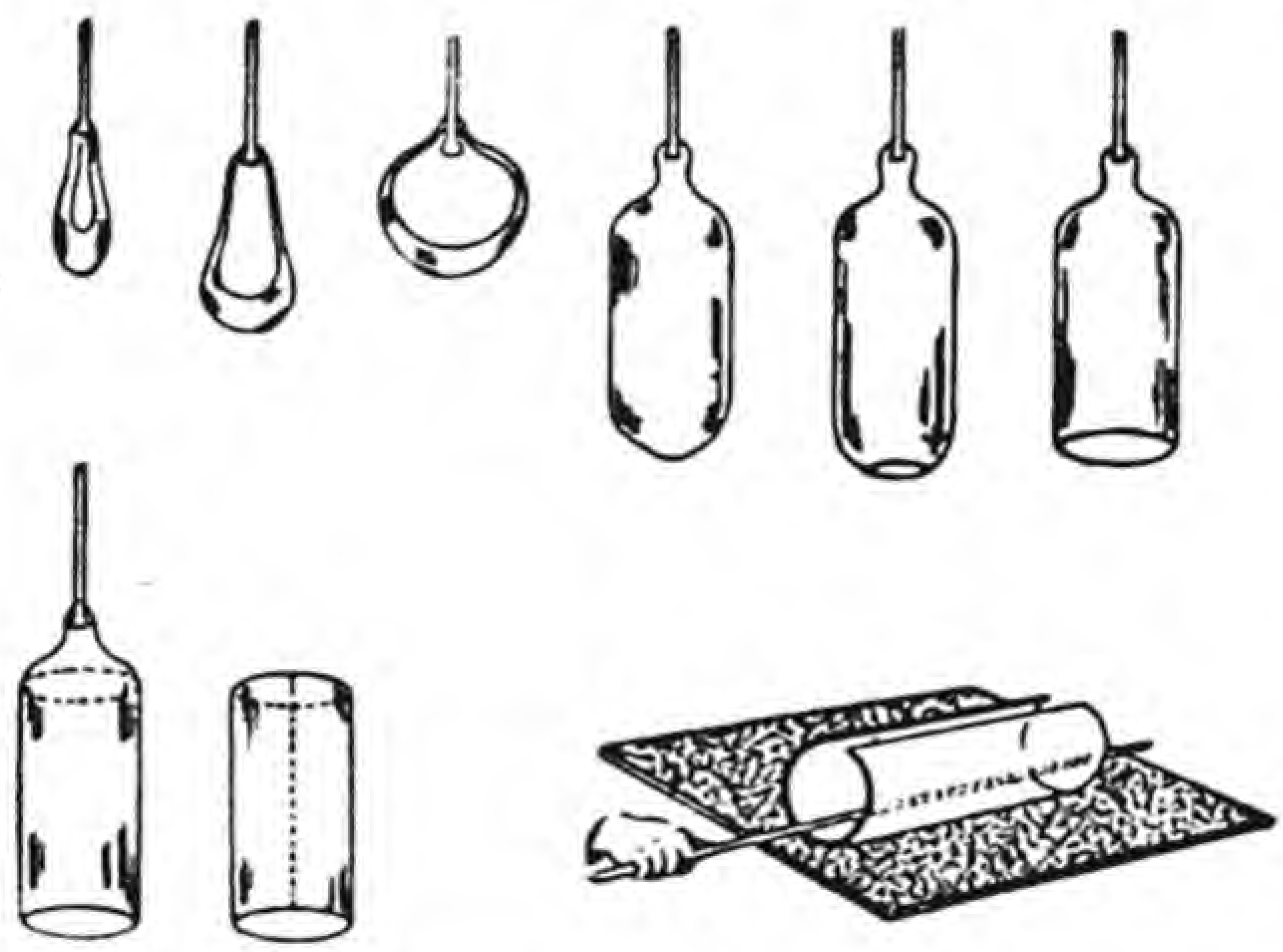


FIG. 136.—*One way of making sheet glass. A long bulb is blown, the ends are cut off, so that we have a glass cylinder, and this cylinder is then split and flattened out on a hot plate.*

can be heated in a flame and then plunged into cold water without cracking, which makes it very valuable in the laboratory. The reason that ordinary glass cracks if quickly heated, say by suddenly putting boiling water into it, is that one side of the glass gets very hot and wants to expand, while the other is cold, and wants to stay as it is. The stress of the struggle breaks the glass. Quartz glass, however, is one of the few substances that have the peculiar property of not expanding when heated, so that this stress does not take place when one side of a piece is hot and the other side cold.

CHAPTER VI

ORGANIC CHEMISTRY: HYDROCARBONS AND CARBOHYDRATES

The Peculiarities of Organic Compounds—Carbon and Its Properties—Petroleum and the Paraffins—Carbohydrates: Sugars, Starches, and Cellulose

THE PECULIARITIES OF ORGANIC COMPOUNDS

WE have said that organic chemistry deals with things produced by living matter, and this is a good beginning, though it is not the whole story. A hundred years or so ago it was believed that there was something very special about anything manufactured by life, that made it different in its nature from mineral matter—that is, from such things as metals, rocks, or the salts found in deserts. It was supposed that a special *vital force*, as it was called, which could not be imitated in the laboratory, was necessary to build up such things as urea, indigo, and sugar, which are substances formed by living animals or plants. To-day, however, ways have been found for making all these things from inorganic matter, by which is meant stuff that has never had anything to do with life; and, although there are thousands of substances in the body which we cannot yet make in the laboratory, we know that this is not because it is impossible to make such things, but because we are not yet clever enough. If you see a beautiful Chinese ivory carving you do not think that there is something absolutely different about Chinamen which enables them to make it: you know that,

although you cannot make one like it, there is no reason why if you, or a friend of yours, spent enough time and patience you should not succeed. In the same way, although life makes thousands of products that we cannot make in the laboratory and others that we can only make with difficulty, we have had enough success in making organic substances to be able to say that as a general rule substances built up in the living body or the living plant can also be built up in flasks and tubes from matter that never was living.

What is there, then, that really makes the organic chemicals—say, sugar—very different from the inorganic chemicals, like salt? In the first place they all have carbon in them, and usually quite a lot of carbon atoms in one molecule. Cane sugar, for instance, has twelve such atoms. Then, again, practically all organic chemicals contain hydrogen. Some contain only these two kinds of elements; others contain in addition either oxygen, or nitrogen, or both. These are the chief things that we find: there are organic compounds with metals in them as well, but they do not form one of the chief classes, although soap is such a compound, for it contains either sodium or potassium.[1]

So much is carbon the real backbone of organic compounds that some people say that organic chemistry is the chemistry of the carbon compounds. This is not quite correct, because carbon monoxide and carbon dioxide and carbon disulphide, which all contain carbon, are generally classed as inorganic, but it is a statement that gives the right general idea.

Let us see how we can show that an organic substance contains carbon. Suppose that we take a lump of sugar,

[1] We have learnt enough chemistry by now not to be surprised that there is no outward sign of the properties of the metal in the compound.

white and shining and sweet, it does not look as if more than forty per cent. of its weight were black tasteless carbon, as it is, while the rest is oxygen and hydrogen in the same proportions as they are in water, two atoms of hydrogen to every one of oxygen. Let us, however, put the sugar in a test-tube and heat it. After a time it melts: if we then stop the heating and let it cool we get a pale yellow substance—this is what is called barley sugar, although it has nothing to do with barley.[1] If we go on with the heating (or, better still, leave the first lump and take a second lump for our further heating), we shall find that steam begins to come off and condenses in drops on the side of the tube, while the sugar turns brown. The steam represents oxygen and hydrogen, combined in the form of water, being driven out of the sugar: the brown mass is called caramel, and forms the main part of the sweets called caramels. If the sugar is still further heated it swells up and forms a black mass, which is carbon.

Another way of showing the carbon in sugar is to add strong sulphuric acid:[2] the sugar gradually goes black, for the acid takes away the oxygen and hydrogen, and leaves the carbon as a black fluffy mass. This is a very simple and striking experiment.

The best way, however, of proving that there is carbon in an organic chemical is to burn it with a supply of oxygen and show that carbon dioxide is formed. The easiest way of supplying the oxygen is to mix the substance with about three times its weight of dry cupric oxide powder.

[1] It is so called because it used to be made by boiling sugar with a preparation of barley.

[2] The experiment succeeds best if the acid is slowly poured on to sugar to which about half its weight in water has previously been added.

Cupric oxide is a compound of copper and oxygen, with one atom of oxygen to one of copper; it is often known as black oxide of copper. When heated with any organic stuff it gives up part of its oxygen, and becomes an oxide of copper in which there is less oxygen, namely, only one atom of oxygen to two atoms of copper. In some cases it gives up all its oxygen, and becomes just copper. The mixture of substance, say cotton-wool or paper, and oxide is put in a hard-glass test-tube (ordinary test-tubes

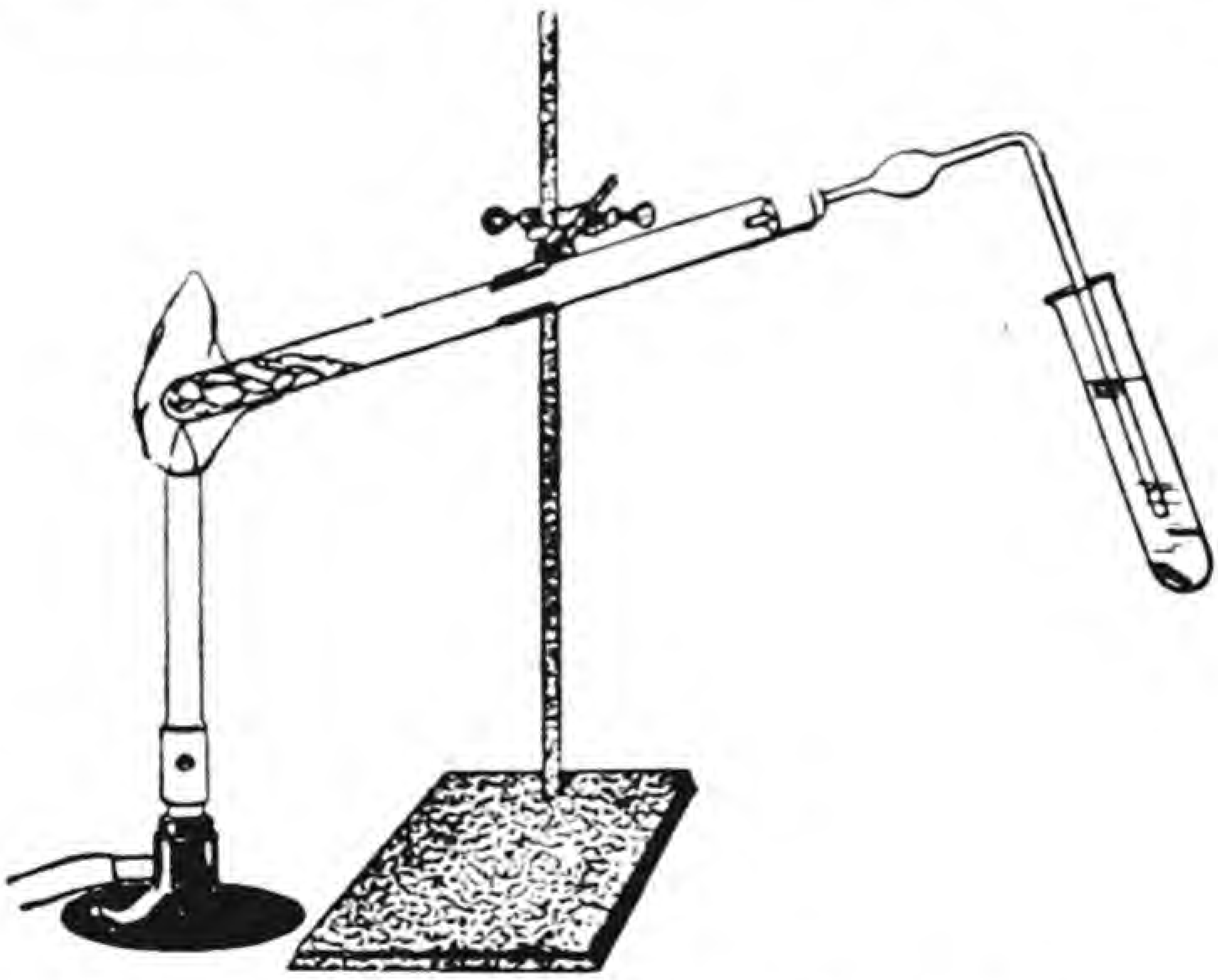


FIG. 137.—*Testing for carbon.*

are made of what is called soft-glass, which melts too easily for this experiment), closed with a cork, which is fitted with a bent tube, the end of which dips into lime water (Fig. 137). When the tube is strongly heated, bubbles of gas pass into the lime-water, which goes milky, a sign of carbon dioxide. If the substance is one which contains no carbon—say salt or caustic soda—no carbon dioxide can be formed, and the lime-water stays clear.

We have said that all organic compounds contain

carbon. The peculiar chemical property of carbon atoms is that they can join up with one another in long strings, or, in certain compounds, rings. We do not find other atoms behaving in this way to anything like the extent that carbon does. There are no molecules which contain strings of sodium atoms, or iron atoms, or sulphur atoms. Just as, in the world of vehicles, such as lorries, motor-cars, wheelbarrows, farm carts, railway carriages, and so on, there is only one class, namely railway carriages, which is found joined up in lines, so in the world of atoms, carbon atoms are distinguished from the others by the easy way in which they join to one another. The consequence is that we often find very large numbers of carbon atoms in an organic molecule, whereas in inorganic molecules we only occasionally find as many of one kind of atom as eight, while in the more ordinary inorganic molecules there are generally not more than four atoms of a kind. The molecule of salt, as we have seen, is just one atom of sodium and one of chlorine, but the molecule of sugar contains twelve atoms of carbon, as well as twenty-two of hydrogen and eleven of oxygen. The carbon forms the backbone and holds the rest together.

Carbon and its Properties

Carbon is a very remarkable substance, which exists in a number of very different forms. Soot is carbon. It is a soft black substance which, as everybody knows, collects in chimneys. The wood or coal ordinarily put on the fire contains carbon, and when they are burnt most of this carbon combines with oxygen to form carbon dioxide, but some of it is not burnt, as we explained in Book I,[1] and forms smoke, which settles in the chimney

[1] On p. 35.

as soot. Charcoal is another form of carbon: it is formed when wood is strongly heated without catching fire. You can make little pieces of charcoal by putting wood shavings in a hard-glass test-tube and heating them over a Bunsen flame. Certain gases and vapours are driven off by the heat, and the hard black substance left is charcoal. In the old days it was made by building a great heap of wood with a kind of chimney in the middle, setting it alight and covering it with turf or soil to keep out the air and prevent it burning freely, so that it was baked, just as it is in the test-tube. This was the job of the charcoal-burners who play so great a part in many of the old fairy tales. The craft of charcoal burning still lives on in some parts of England, in particular Kent and Surrey, but nowadays charcoal is usually made by heating the wood in closed iron vessels, known as retorts, so that the gases and vapours that come off can be collected, for they contain many substances that can be turned to good use, such as wood vinegar (acetic acid), wood spirit (methyl alcohol), acetone, and tar. Charcoal is still used for fuel in France and other countries where forest trees are plentiful. It is one of the three things of which gunpowder is made, the other two being sulphur and nitre.[1] Another form of carbon, which is denser and harder, collects in the retorts in which coal is heated to make gas.[2] Still another form is lamp-black, which is the soot which collects in oil lamps. It is made on a large scale by burning crude oil, and collecting the soot on coarse blankets, and it is used for making printers' inks. Finally, coke is also a form of carbon.

[1] In the proportions of 15 parts of charcoal, 10 parts of sulphur, and 75 parts of nitre. Nitre is also called saltpetre.

[2] See p 245.

All these forms are something like soot, some being very soft and loose, and others denser and harder, but all are the same dull black substance. It is just a question of how it is packed together. There are, however, kinds of carbon that are of quite a different nature. Graphite is a black shining substance, which is greasy to the touch: it is made up of crystalline flakes which slip easily over one another. Pure graphite is just carbon. It is used in making lead pencils, from which it gets its name, for the

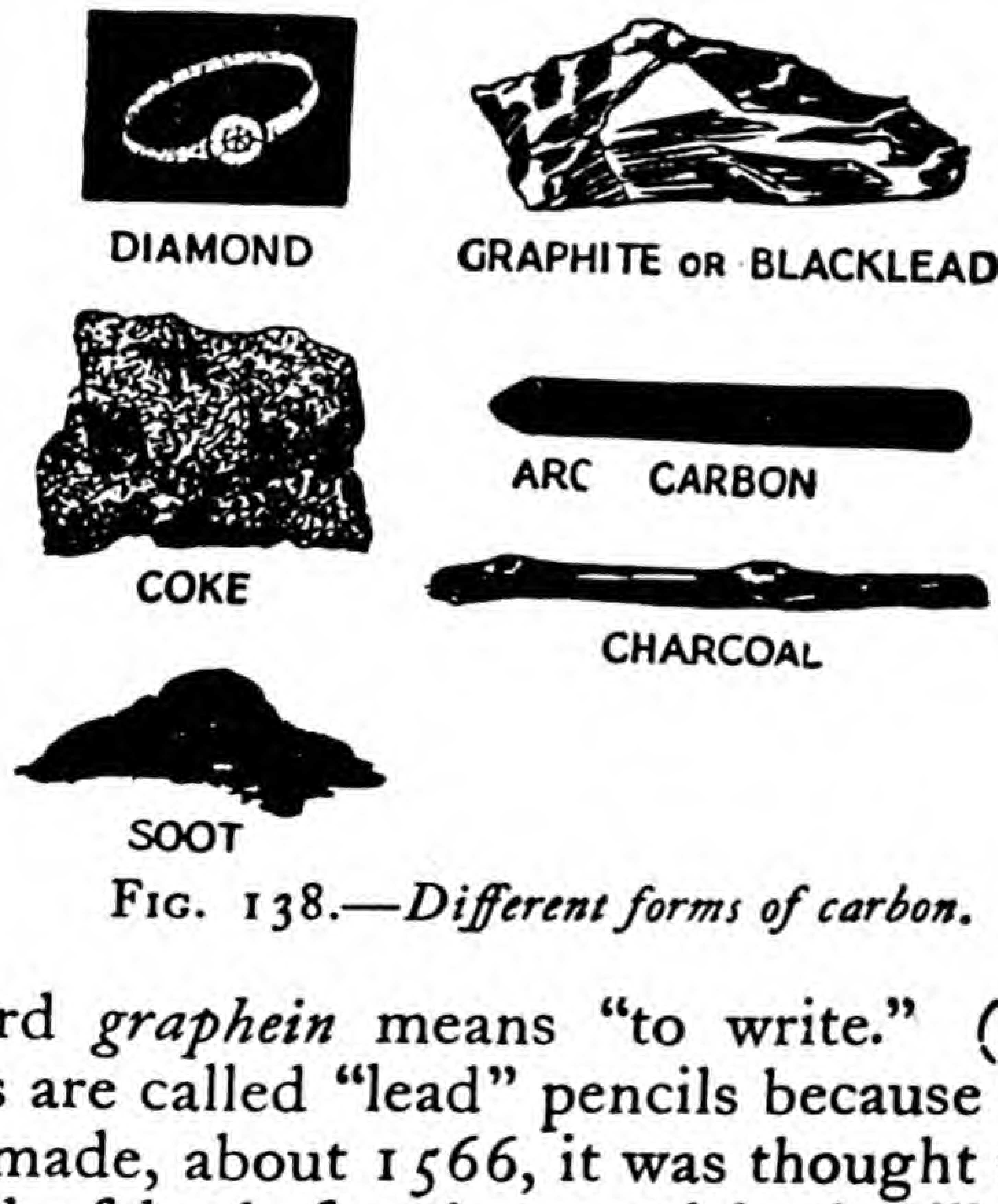


FIG. 138.—*Different forms of carbon.*

Greek word *graphein* means "to write." (By the way, the pencils are called "lead" pencils because when pencils were first made, about 1566, it was thought that graphite was a kind of lead, for the metal lead will mark paper. The "black-lead" used for blacking stoves is also made of graphite and has nothing to do with lead.) Graphite is also used instead of oil for lubricating certain kinds of machinery. Pencil leads are not made of pure graphite but of a mixture of this substance and clay. In cheap pencils

there is often a good deal of clay, and not very good clay at that.

There is, lastly, one much more surprising form of carbon—diamond! A diamond is just carbon which has crystallised in a certain way. If a diamond is strongly heated in oxygen it burns, and forms carbon dioxide and nothing else, which proves that it must be carbon. This is an expensive experiment, and you are not likely to have an opportunity of performing it. Another proof that diamonds are only carbon is that very small diamonds have been artificially made from carbon by making it crystallise under very great pressure. The diamonds made in this way are so small, and the cost is so great, that the experiment is of scientific interest only, and does not pay.

You may well be puzzled, and ask why if graphite and carbon and diamond are just carbon, and nothing else, they are such different substances. When we say that they are all carbon, we mean that they are made up of atoms of carbon, and of nothing else, and that all atoms of carbon are the same. The explanation of the difference in properties is that the atoms are built together in different ways in the different substances. Suppose that you have a large number of Meccano strips, all the same size. We can pile them in a loose heap, or push them together in a closer heap, or we can fasten them together in regular ways,

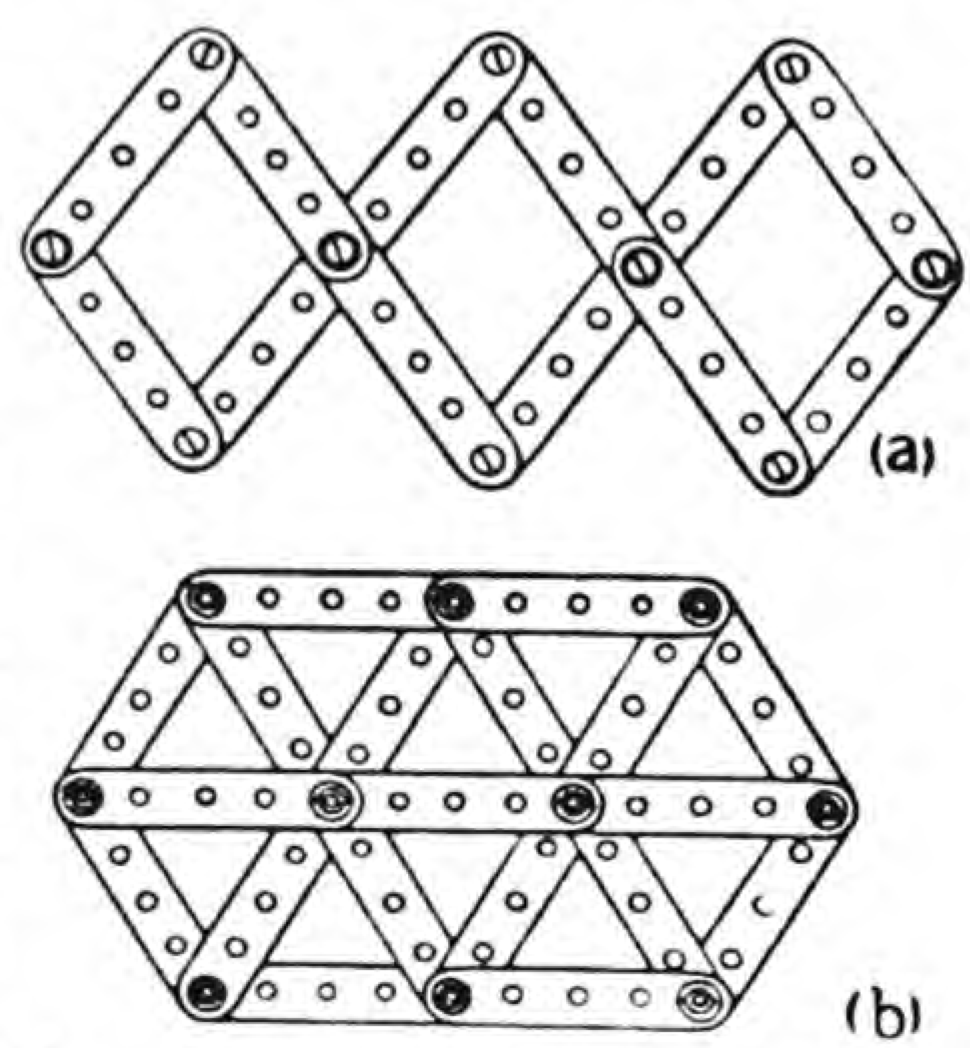


FIG. 139.—*Two different structures, built with the same kind of Meccano strip.*

such as that shown in (*a*) or that shown at (*b*) in Fig. 139. The form (*a*) has no strength and easily squeezes up, if we push the ends together; the form (*b*) is strong, and will stand a push at the ends. Now let us think of our carbon atoms. We can have them arranged together without order, as in soot or charcoal. On the other hand, we can have them arranged in regular structure, which we call crystals. We have two such regular structures, one soft which we call graphite, and one hard, which we call diamond. The patterns in which the carbon atoms are put together are not the patterns which we have made with Meccano strips: we have only used these metal pieces to show the kind of thing we mean when we talk of carbon atoms being arranged in different ways. The actual arrangement of atoms in the diamond and in graphite is more complicated. The thing to remember is that when we know the kind of atoms of which a substance is made up, we do not know all about it, even if there is only one kind of atom: the way the atoms are arranged in layers is also important.

Carbon is not the only element which can exist in different forms. Sulphur, for instance, is another example. It can be bought in sticks or rolls or in powder. If a little of the powder, say, is dissolved in carbon disulphide, a liquid of a very powerful and disagreeable smell, and the liquid is then left to evaporate in a flat dish, beautiful crystals of sulphur will be formed. Again, if sulphur is heated in a test-tube until it melts, and then still further heated until the liquid nearly boils, and if this liquid is then poured into cold water, a mass is formed which can be squeezed into different shapes like clay or plasticine. It is just another form of sulphur, called plastic sulphur, which after a time changes back to ordinary sulphur.

Many properties of an element, then, do not depend only on what it is, but also on how it is built up. We must now go back to carbon, and consider a few of the many compounds in which carbon atoms play a principal part.

Petroleum and the Paraffins

There is a very simple and very important class of organic compounds which contain only carbon and hydrogen—no oxygen, remember. Such compounds are called hydrocarbons. The most important kind of hydrocarbons are the bodies called paraffins. This name tells us something about the general characters of these substances, for it comes from the Latin words *parum*, which means "little," and *affinis*, which means "connected with," the name suggesting that they do not readily connect or combine or even mix with other chemicals. The paraffins do not dissolve in water, and the ordinary acids, such as sulphuric and nitric acid, for instance, which act so vigorously on metals, do not act upon them, nor do the ordinary alkalis.

We are all familiar with the word paraffin as used in oil shops to describe a kind of lamp oil. This paraffin oil is a mixture of what organic chemists call pure paraffins, but it will do to prove how unsociable, if we may use a word applied to human beings who do not readily combine or mix, these substances are. Everybody knows that paraffin oil will not dissolve in water, but we can also put a little in a test-tube and put acids or alkalis on it, without anything happening. The digestive juices of the human body are also chemicals which do not act upon paraffins, but do, of course, act upon vegetable oils, such as olive oil. No oil of the paraffin kind can be made into food for man or

beast. They cannot even be used as food material by bacteria, and so do not go "bad."

The natural source of most paraffins is the mineral oil called petroleum, which is found in great quantities in certain parts of the earth, especially in the United States, the Russian lands around the Caspian Sea, Venezuela, Mexico, and Persia. It has been formed from the remains of plants and animals that lived millions of years ago, long before historic times. While the buried bodies of the great prehistoric lizards and prehistoric

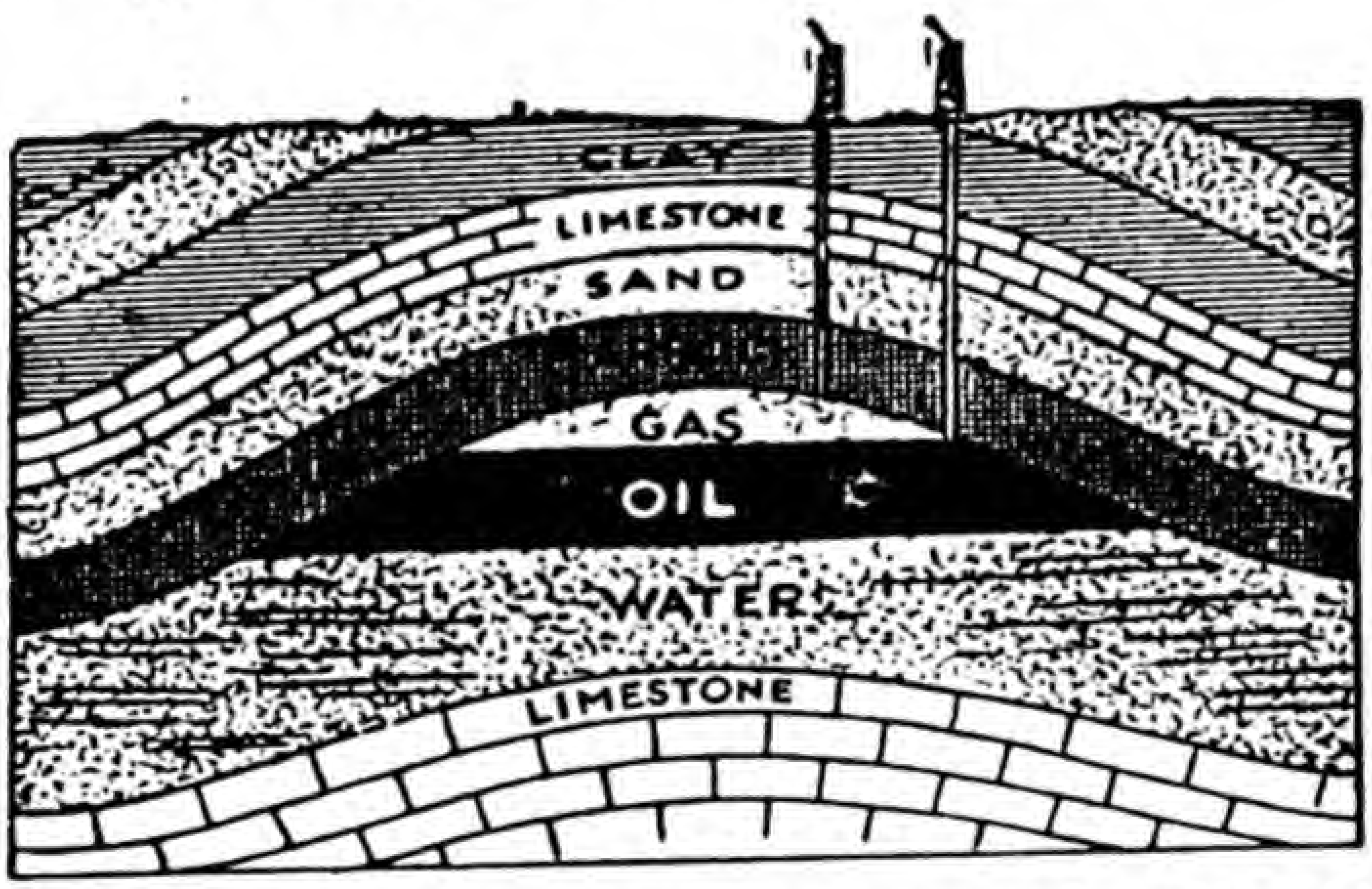


FIG. 140.—*Section through the earth in an oil field. The oil is held in a thick layer of sand, between two different kinds of rock. It floats on a layer of water while gas collects above it, all in the sand.*

marsh plants may account for some of it, it is generally believed that the greater part must have been formed from minute sea life, like the diatoms mentioned in Book I, and tiny seaweeds. It must be remembered that millions of years ago the sea spread over vast areas that are to-day continents. In any case, the origin of petroleum is the organic matter of life of past ages. The petroleum is found only in certain parts of the world, where the underground layers or strata, as they are called,[1] are suitable

[1] See Chapter VIII.

for storing it. There must be sand or porous rock to hold the oil, much as the wet sand at the edge of the sea holds water. In some places the oil floats on water, which lies in the sand and is itself held by a layer of rock, as shown in the picture: at other places the oil is kept in by a layer of rock. Over the oil is a lid of rock through which the gases that collect cannot escape. Owing to these gases the oil is generally under pressure, so that if a hole is bored

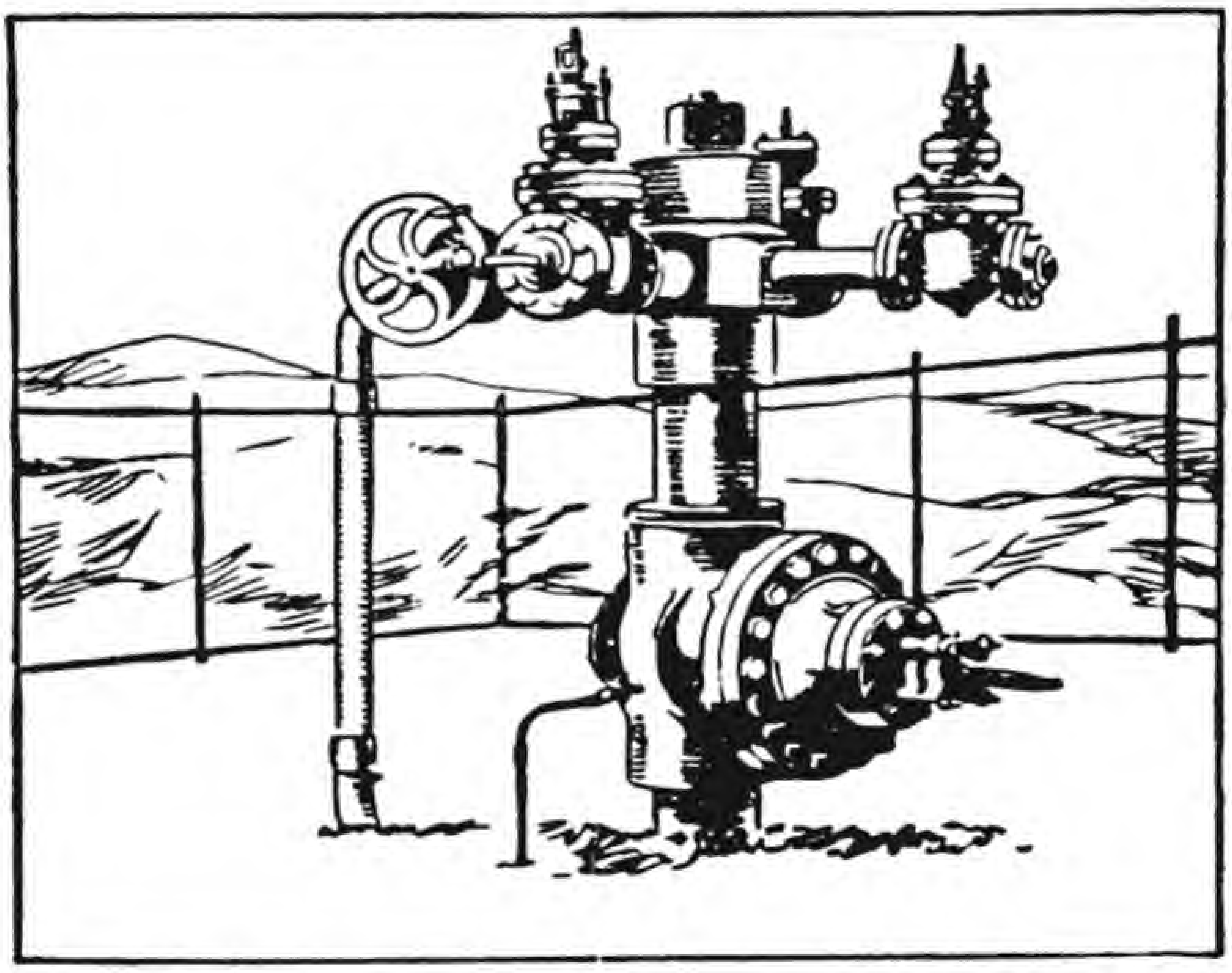


FIG. 141.—*Petroleum well-head.*

down through the earth and the rock lid, as soon as it reaches the underground lake of oil the oil shoots out, just as the water does out of a broken water-pipe in the street, only harder, since the pressure is greater. The hole, as it is made, is lined with an iron casing, to which a head is quickly fastened to prevent the oil running to waste. Such a "flow-head," something like a gigantic bath tap, is shown in Fig. 141. It is of the modern type used in the Persian oil field.

One of the simplest ways of drilling for oil is illustrated in Fig. 142. The heavy piece of hard steel, or bit, as it is called, which the man in the middle of the picture is examining, is lifted by a wire cable and dropped, again and again, so that it pounds its way through the earth and rock. In another method a kind of drill is used. Holes of surprising depth, up to a mile and a half, have been drilled for oil. A petroleum well in which the oil is gushing out

FIG. 142.—*A drilling rig, as it is called, used in boring oil. The steel bit, which the man in the centre is examining, is lifted by a cable, and dropped from a great height.*

under natural pressure is called a flowing well: after some time the pressure goes down, and the oil will not come up by itself, but has to be pumped up by special means. The great underground oil lakes of California are covered closely with the frameworks, called oil derricks, which are erected for drilling (Fig. 143).

Petroleum, as it is produced from the earth, is a very thick liquid, something like dark treacle in appearance,

and black or greenish-brown in colour. From it are prepared various products, which are separated by distillation. The crude oil is put into a great steel vessel, heated by steam, and the vapours which rise from it are condensed and collected, just as steam is in the distillation of water described in Book I. The difference is that in the crude petroleum we have mixed together a whole series of different chemical substances, called pure paraffins, which

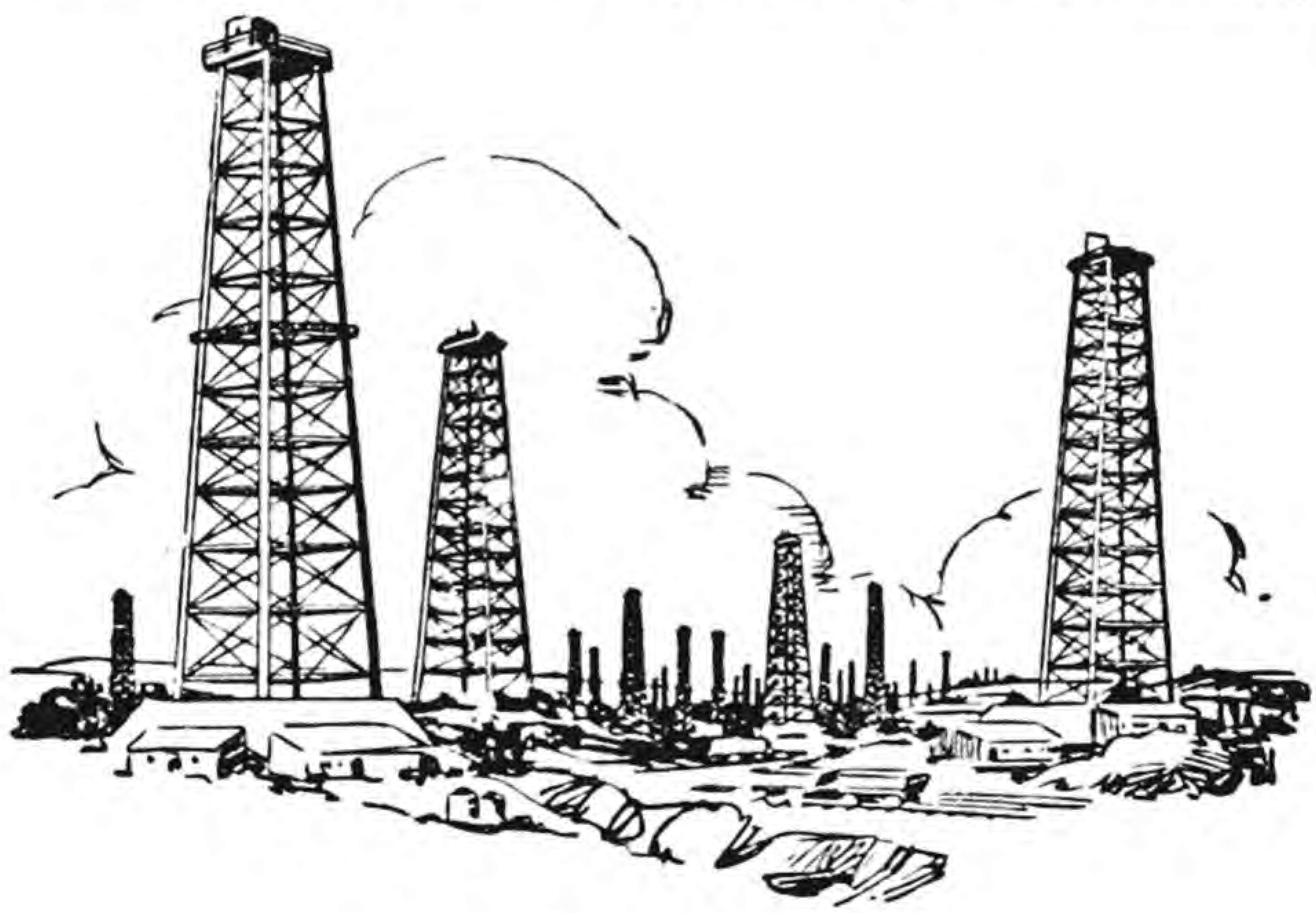


FIG. 143.—*An oil field.*

boil at different temperatures. Advantage is taken of this fact to separate out different products, of which the chief are the following: motor spirit (usually called petrol in this country, and gasoline in America); naphtha (notice the "phth"—this is a good word in spelling competitions), which is used as a solvent and for flares; benzine, also called benzoline, which is a solvent used in cleaning;[1]

[1] It must not be confused with benzene, a very important pure organic liquid, not a mixture, which is discussed later on.

kerosene, or paraffin oil, which is the ordinary oil used in lamps and cooking stoves; light bearing oil, heavy bearing oil and steam cylinder oil, which are all used by engineers. These products are given in order of boiling points, the first one having the lowest, and the last the highest, boiling point. When, in the process of separation, they have all been boiled away from the crude oil which was put in the retort in the first place, about one-third of the crude oil will still be left in the retort. This oil of high boiling point which is left behind is used as a fuel in ships and factories.

This is the kind of way in which the petroleum is divided up into products used for different purposes. In general, the lower the boiling-point the thinner, or more fluid, the liquid—in other words, the more easily it runs. Petrol is much more fluid than lamp oil, and lamp oil more fluid than fuel oil, which may be as thick as treacle. The products of low boiling-point, that is, the different petrols, evaporate, of course, quite freely at ordinary temperatures, and the vapour, mixing with the air, makes an explosive mixture which easily catches fire. That is why great care should always be taken never to have an open flame or sparks near petrol.

Collections of natural gas are often found in or near petroleum fields, as illustrated in Fig. 140. This natural gas was at one time wasted, but is now being tapped with pipes, and burnt for general heating purposes, in many parts of the world. At Pittsburg, in the United States, natural gas is used for the furnaces in the great iron works. The yearly production of natural gas in the world amounts to over a million million cubic feet, nearly all in the United States; this is nearly four times as much as is produced from coal.

There is a kind of flaky rock, sometimes something like a soft slate, sometimes dark like coal, called shale. Many shales are rich in oil, and often smell of it: they are a natural source of paraffins, especially the solid called paraffin wax. Shale is plentiful in Scotland and elsewhere, and very large quantities of this wax are prepared from it by distillation. The wax is used for candles, and for preparing insulating paper for electrical purposes. The cups and cartons in which liquids like cream are sold are soaked in melted paraffin wax to make them water-tight.

We must now consider what it is that the chemist means by *a* paraffin. A paraffin is a pure chemical substance, not a mixture of pure chemical substances. The simplest paraffin is not a liquid at all, but a gas called methane, or, more popularly, marsh gas, for the reason that the bubbles which can be seen rising in ditches and marshes generally consist of this gas. The famous chemist Dalton collected it by filling a wide-mouthed bottle with water in a ditch, turning it upside down under water and stirring the mud at the bottom with a stick: some of the rising bubbles were caught and could be carried away in the bottle. In the Town Hall of Manchester, the town where Dalton lived and worked, there is a picture of him collecting marsh gas in this way.

Methane is, unfortunately, produced naturally not only in petroleum deposits and in marshes and ditches, but also in coal mines, where it often comes out of cracks in the coal, and is called by the miners fire-damp. Although it will burn quietly if lit when it first meets the air, if it becomes mixed up with air it explodes with great violence on meeting a light, behaving in these respects, in fact, just as ordinary lighting gas does. A mixture of about 10 per cent. of methane and 90 per

cent. air, for instance, is very dangerous, and the chance lighting of such methane-air mixtures has in the past led to terrible disasters in coal mines. Modern precautions, and in particular the safety lamp described in Book II,[1] have gone far to make mines safe against fire-damp. One large modern colliery in Yorkshire gives off 700,000 cubic feet of methane every twenty-four hours, but it is mixed with so much air as to be neither dangerous nor worth recovering for heating purposes. The danger comes when there is a sudden rush of the gas from a large crack or opening. Methane, again, makes up the chief part of the natural gas that is found in many parts of the world.

Methane is a gas which burns easily with a non-luminous (pale blue and transparent) flame: ordinary coal-gas, as supplied to houses in pipes for cooking and lighting, contains between 25 and 35 per cent. of methane. The molecule of methane consists of one carbon atom and four hydrogen atoms. We can imagine a carbon atom as consisting of a black ball with four wires sticking out of it, with a little ring on each into which the wire of another carbon atom can fit. Of course a carbon atom is really nothing like this, but this sort of model will help us to remember how it behaves chemically. If we stick a small white ball with a hole in it, representing a hydrogen atom, on each wire, we have a model of methane.

The simplest paraffin, then, is CH_4, represented in the top left-hand corner of Fig. 144. A picture of the next paraffin may be formed from it by adding one carbon atom and two hydrogen atoms. We take, in our model, a carbon with a hydrogen fixed to each end of two

[1] P. 117

opposite rods. To fit it to the methane molecule we must take off one hydrogen to make a place for one arm of the new carbon atom, which we now fix on. One arm of the new carbon atom is then unoccupied, and we place the spare hydrogen atom on it. We get the model shown at the top, on the right, in Fig. 144, representing a molecule of the gas ethane, C_2H_6, which resembles methane closely in its chemical properties. You will see that one arm of each carbon is occupied in holding the two carbons together, while every other place is taken by a hydrogen atom.

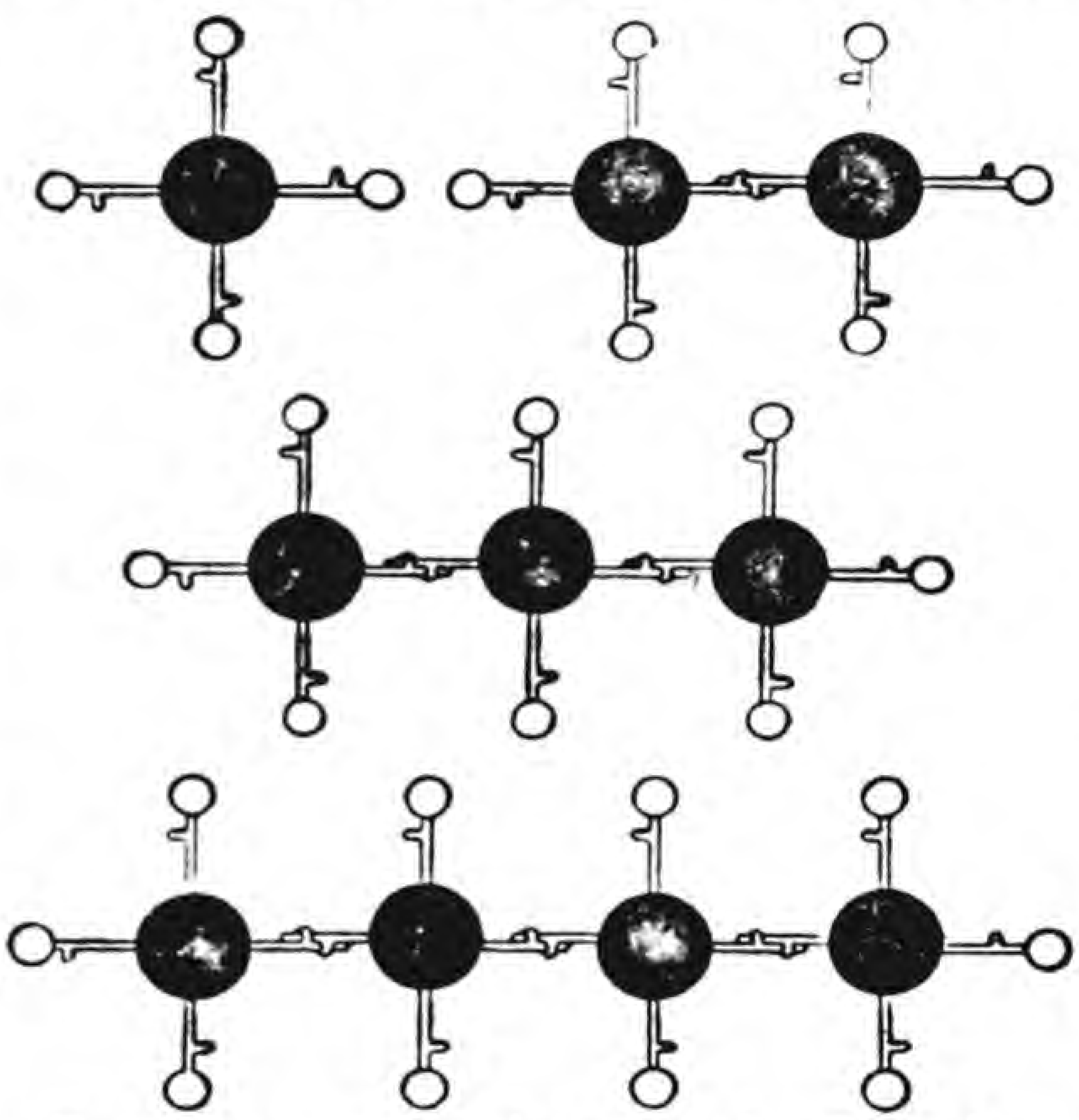


FIG. 144.—*Models of the first four paraffins.*

All the other paraffins can be formed from ethane by adding one carbon and two hydrogens, CH_2, at a time. With our model we separate the two carbons of ethane, and we put in the CH_2, as shown in the middle of Fig. 144: we then have C_3H_8, which is known as propane. The 4-carbon paraffin is also shown in Fig. 144: it is written C_4H_{10}, and is called butane. This is not the end of the series by any means, for paraffins are known up to $C_{62}H_{126}$. To find the number of hydrogen atoms in a paraffin we merely have to double the number of carbons, and add 2 for the two extra hydrogens, one at each end. Thus the 8-carbon paraffin, called octane, is $C_8H_{16+2}=C_8H_{18}$.

The first four paraffins are gases.[1] The next one, pentane, C_5H_{12}, is a liquid that boils very easily, and the following ones are liquids whose boiling-points get higher and higher until we come to hexadecane, $C_{16}H_{34}$, which is a solid that melts very easily. After that the paraffins are all solids, whose melting-points get higher and higher as we go up the series.

The different products that are prepared by the distillation of petroleum are, each one of them, mixtures of pure paraffins that are neighbours in the series of paraffins which we have just described. Thus ordinary petrol is mainly a mixture of the paraffins with six, seven, and eight carbons, written C_6H_{14}, C_7H_{16}, C_8H_{18}, and called, respectively, hexane, heptane, and octane, while paraffin wax is a mixture of paraffins from $C_{18}H_{38}$ to $C_{43}H_{88}$.

Carbohydrates: Sugars, Starches, and Cellulose

There is a very important class of organic bodies called carbohydrates. They consist, like so many other classes in organic chemistry, of carbon, oxygen, and hydrogen, but the special reason why they are called carbohydrates is that the oxygen and hydrogen occur in them in the same proportion as they are in water, two atoms of hydrogen to one atom of oxygen. Thus a molecule of ordinary cane sugar (table sugar) is written as $C_{12}H_{22}O_{11}$—22 atoms of hydrogen to 11 of oxygen, or 2 to 1; a molecule of glucose is written $C_6H_{12}O_6$, once more 2 atoms of hydrogen to 1 of oxygen. As an example of a carbon, hydrogen, and oxygen body which is *not* a carbohydrate we may take ordinary alcohol, C_2H_6O, where there are 6 atoms of

[1] That is, at ordinary temperatures. They can, of course, be made liquids by cold.

hydrogen to 1 of oxygen; or vanillin,[1] which is the substance that gives vanilla its characteristic taste, written $C_8H_8O_3$. So now it is quite clear that you must not just say that a carbohydrate is a substance which contains carbon, hydrogen, and oxygen, neither must you confuse it with a hydrocarbon, which, as we have seen, is a substance that contains only hydrogen and carbon.

One of the best-known carbohydrates is ordinary sugar, which chemists call sucrose. It is prepared either from the juices of the sugar-cane, or from the sugar-beet; there is no difference that can be detected by taste or smell between cane sugar and beet sugar, if they have been properly purified, and there is, in fact, no chemical difference, any more than there is in the pure iron made from different kinds of ores.

The sugar-cane has a tough thin skin with joints on it, like bamboo, and a stringy or fibrous inside, something like the cane of which cricket-bat handles are made, in which the juice is stored. To squeeze out the juice the cane is passed through heavy rollers, some with grooves in them, and some armed with short knives, which crush and shred it. The juice so collected is purified, and then placed in pans to evaporate the water away and leave the solid sugar.

If the juice were boiled down in open pans the sugar would be spoiled by the high temperature. As we learnt in Book II (p. 134), a liquid boils at a much lower temperature if the pressure of the air above it is made low,

[1] Vanillin, which is prepared chemically, is generally used to-day to flavour ices and such things, instead of the natural vanilla, which is extracted from the pod of a kind of tropical vine. This is a good example of how organic chemists can make substances that at one time could only be obtained straight from living things.

as the vapour can then escape more readily. For the evaporation of the juice, which contains about 13 per cent. of sugar, vessels called vacuum pans are therefore used. These are large closed vessels, with a tube leading out of the top through which the air and steam are pumped away, the steam being condensed in the usual way by cold water. The pressure is reduced to about a seventh of the full atmospheric pressure, with the result that the juice boils at about 55° C., instead of at a temperature above 100° C., and the sugar is left as a mass of crystals. If nothing is done to prevent it, the sugar will be brown, but usually the juice is treated with charcoal, or in some other way, to remove the colour, so that white sugar may be produced.

(From Dr. Francis Maxwell's "Economics of Cane Sugar Production.")

FIG. 145.—*Sugar-cane.*

The sugar-beet is something like ordinary red beetroot in shape and size, but is white and turnipy in appearance, both outside and when cut. It was in 1747 that it was first found that the root contained sugar, and the amount of sugar

in the beet of those days was only about 6 per cent., but by careful cultivation, and by selecting the plants with the most sugar to breed from, the amount of sugar has been increased, until to-day it is something like 16 per cent., and special varieties of beet contain as much as 20 per cent. To obtain the sugar the roots are sliced and left to soak in water, which extracts the juice. After filtering and purification the juice is evaporated down in vacuum pans, just as the cane juice is. On the Continent, and in some parts of North America, sugar is made extensively from the sugar-beet, and sugar is manufactured in England, to some extent, in this way. In other parts of the world where sugar is produced, such as South Africa, the British West Indies, Queensland, Java, and Hawaii, it is made from cane.

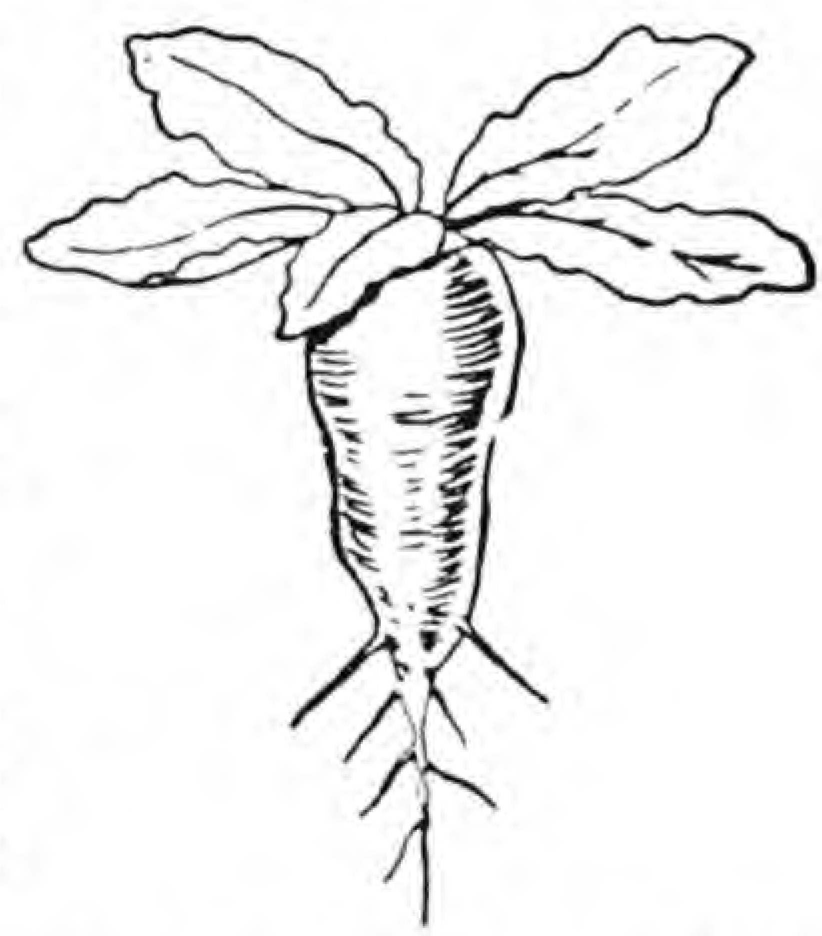


FIG. 146.—*Sugar-beet.*

Sugars, somewhat different in chemical composition from sucrose, can be obtained from other sources. Glucose is a sugar which occurs in ripe fruits, but can be obtained more cheaply from starch, as we shall see shortly. It is not so sweet as sugar, but is often used in cooking and given to invalids, as it is more quickly absorbed by the body than cane sugar. Lactose is a sugar that can be obtained from milk. Maltose is the sugar formed in malt, to be mentioned when we deal with fermentation.

All these sugars are very similar in chemical composition, maltose and lactose, for example, having actually the same numbers of carbon, hydrogen, and oxygen atoms in the molecule, but the arrangement being somewhat different. This kind of thing often happens in these

organic molecules, which have lots of atoms, and it is not surprising. If, for instance, we were to give out sets consisting of three different kinds of meccano parts, so many of each kind, to different boys, each set being exactly the same, and if the boys were told to build something, using all the set, it is clear that we should get different structures, especially if there were fairly large numbers of each part.

Starch is an exceedingly important carbohydrate, and there are many different kinds of starches. The molecule of any starch is built up of a number of sets of $C_6H_{10}O_5$. How many sets go to each molecule has not yet been found out: thus the molecule may be $C_{18}H_{30}O_{15}$ (three sets), or $C_{30}H_{50}O_{25}$ (five sets).[1] All green plants contain a starch (as described in Book II, pp. 181-84), but potatoes and other such tubers[2] as, for instance, Jerusalem artichokes, and all grains, such as rice or wheat or maize, are particularly rich in starch. The starch used in laundry work, commonly called just "starch," is rice starch, while the stuff called "cornflour," of which blancmange and such-like sweets are mainly composed, is really maize starch. A certain amount of starch is an important part of our food, which we take chiefly in bread, oatmeal and other cereal foods, such as rice, and potatoes.

Starch is very easy to prepare, as we have only to crush up the plant material which contains it, say potatoes, so as to break the walls of the cells, and mix the pulp with water. This liquid must then be filtered, to remove the

[1] The position is just the same as if you had a model made of meccano parts, and knew that only pieces of one particular set of parts (say that called No. 1 set) had been used to make it, but did not know how many sets were built into it.

[2] Fleshy underground lumps, like potatoes, are generally called tubers.

larger bits of solid, and allowed to settle, when a layer of starch will be formed on the bottom of the vessel. In flour the crushing has been already done for us, so that if we mix flour and water, and knead the mixture in a linen bag, which will act as a filter, the milky liquid that runs through will deposit starch if it is left in a shallow basin. The sticky stuff left in the bag is called gluten: we may remember that "glutinous" is another word for sticky. Gluten, by the way, is a protein, one of the body-building substances mentioned in Book II.[1] Scraped potatoes in water will also form a milky liquid from which starch can easily be obtained by leaving to settle.

FIG. 147.—*Making starch from flour.*

If starch powder be examined under the microscope it will be found to consist of little grains. These grains are of different shape and size in the starch from different substances, as shown in the picture (Fig. 148).

Starches can be converted into sugars by a kind of fermentation, as described in the next section. If starch be boiled with water it takes up more oxygen and hydrogen, in the proportions in which they occur in water, and a syrupy liquid is formed, from which glucose, the sugar mentioned just now, can be obtained in the form of crystals. Actually, in the manufacture of glucose for use in making jam, any starch, such as maize, rice, or potato starch, is heated with hot dilute hydrochloric acid under pressure, but the effect is the same, namely, that the starch in the substance takes up oxygen and hydrogen as just described.

[1] Page 155.

We have seen how plants will yield sugar and starch: the fruits, especially, the sugar; and the leaves and roots, the tubers and the grains, the starch; but there is a third very important carbohydrate, called cellulose, to be considered. This is the commonest of all organic material, since it forms the main part or framework of all plants and

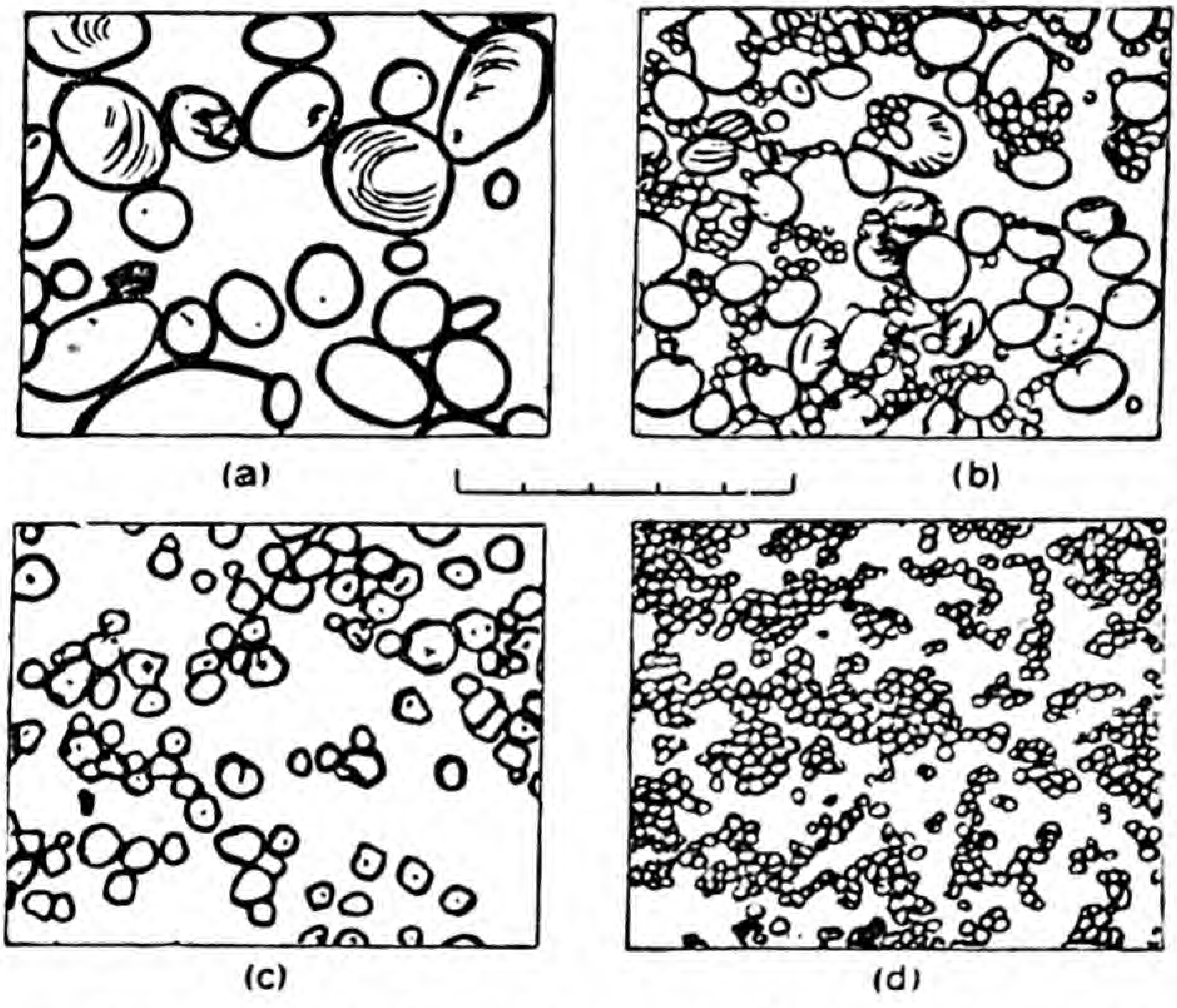


FIG. 148.—*Starch grains from (a) potato, (b) oats, (c) maize, (d) rice. The scale between the four pictures shows five one-thousandths of an inch*

trees. Blotting-paper is nearly pure cellulose, and so is cotton-wool. It is a very complicated substance, built up of carbon, hydrogen, and oxygen in the same proportions as in starch, but in a different way. The molecule of cellulose is built up from several sets of $C_6H_{10}O_5$ just as the molecule of starch is, but the atoms must be arranged in a different way. There are probably different

kinds of cellulose, but even now chemists do not know the exact way in which the atoms are put together to form this substance.

There is one very simple property that distinguishes sugar, starch, and cellulose. Sugar dissolves in cold or hot water: starch dissolves slowly in boiling water, but not in cold, for, as we have seen, it settles from the cold water, and however often we stir it up, it will settle again. Cellulose will not dissolve in either hot or cold water, which is fortunate, or our filter-paper would dissolve if we poured a hot solution on it, and our cotton or linen clothing would disappear if put into hot water. Cellulose is also not dissolved by boiling in dilute caustic soda solution, which will, however, dissolve wool. If, therefore, a piece of stuff which contains both wool and cotton is boiled with caustic soda the wool will dissolve and the cotton will remain. This is a useful test: if a mixture that is said to be wool and cotton is practically unchanged by this treatment you can be sure that there is not much wool in it.

Cellulose forms the walls of the cells in plants, and so can be obtained from all kinds of plants, grasses, and woods. A very large number of important substances are made from it, among which we may mention paper, artificial silks, and some explosives.

Paper is made from various plant fibres; the commoner kinds from wood, better kinds from cotton rags, and the very best from linen rags. Various other plant substances, such as, in particular, a Spanish grass called esparto, are also used for paper making, even straw being used for coarse brown wrapping paper. Linen and cotton are nearly pure cellulose; the rags, after washing, are made into a pulp by being chopped and broken up very fine

under water. In the case of wood it is necessary to separate the cellulose from the tougher stuff, called lignin, which is another organic substance closely related to cellulose. This is done by cutting the logs into small chips and boiling these chips with a chemical that dissolves out the unwanted part. Calcium bisulphite is often used for this purpose, and the process is carried on in huge boilers that will hold 30 tons or more of wood chips at a time. The liquid, containing the dissolved lignin, is drained off, and a pulp, called sulphite wood-pulp, is left. Huge quantities of wood are used up to make this pulp, mainly for newspapers, the figure amounting to 40 million tons a year. Large forests in North America are used for nothing else, and the world's timber is in danger of being exhausted if something is not done quickly to plant new trees.[1]

FIG. 149.—*A huge boiler in which wood is cooked with calcium bisulphite to make pulp for the paper on which newspapers are printed.*

The pulp, whether produced from wood or rags, consists of a wet mass of fibres of cellulose. These fibres have to be matted together, which is done by machinery that first of all conveys the pulp on an endless band of wire-cloth, which passes round two horizontal rollers, so that the top surface is always travelling forward. Here the pulp drains and settles. The thick layer then passes on to rollers, which convert it first into a damp layer, and finally, by further squeezing, into a dry sheet. The rollers act just

[1] See Book II, Chapter VI.

as do the rollers of a mangle for drying clothes. Paper that has been made in this way is spongy, like blotting-

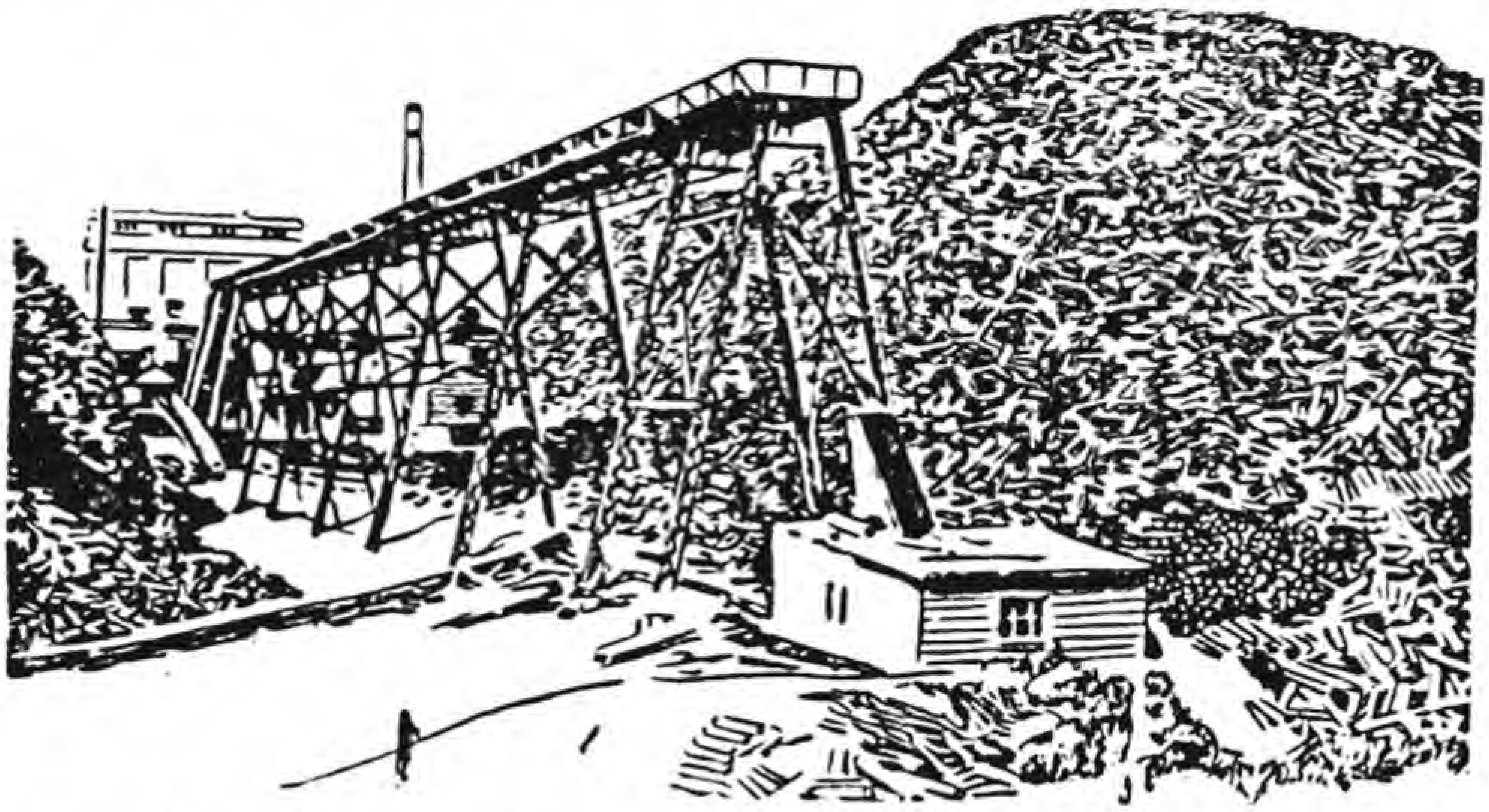


FIG. 150.—*A pile of logs to be made into pulp for paper. This gives some idea of the quantities in which wood is used.*

paper or filter-paper. All writing and printing paper is "sized," that is, certain substances, which put the final

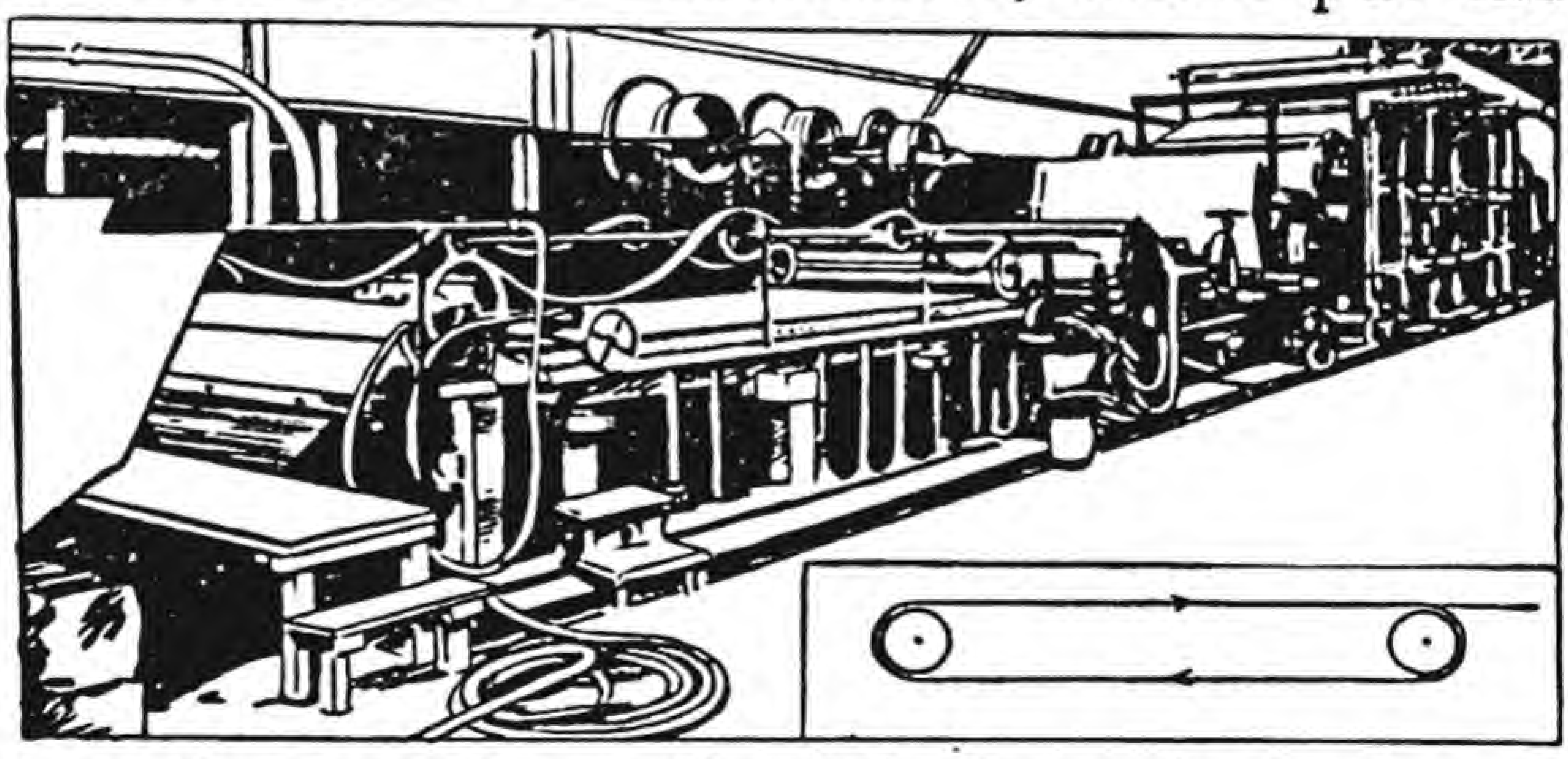


FIG. 151.—*A paper-making machine. The diagram in the corner shows how an endless band works. The material on top of the band is carried from the left on to the little shelf on the right.*

surface in a smooth state which does not mop up ink, are added to the pulp before it goes through the rollers.

Finally the paper is passed between hot rollers to give it a smooth and glossy finish. This is called "calendering" the paper. Your finished writing paper is, then, a mat of cellulose with the tiny fibres coated with size and ironed into smoothness. If a strong light is shone through a piece the fibres can easily be seen with a microscope, as pictured in Fig. 152.

Fig. 152.—*A piece of writing paper magnified 150 times. The cellulose fibres show very plainly.*

Artificial silk is made from cellulose treated in a special way, which makes it into a very smooth, clear, thick liquid. There are at least four different methods of doing this, which are too complicated to describe here. The thick liquid is forced through tiny holes into hot air, or into a liquid (acid in some processes, water in others), which converts the fine jets of cellulose into long silky threads. These are twisted together to form a yarn, or very fine string, which looks like a yarn of natural silk. The transparent sheets of cellophane, which are so widely used for wrapping sweets and tobacco nowadays, are made of exactly the same stuff as is used for artificial silk stockings, squirted through long slits instead of through holes.

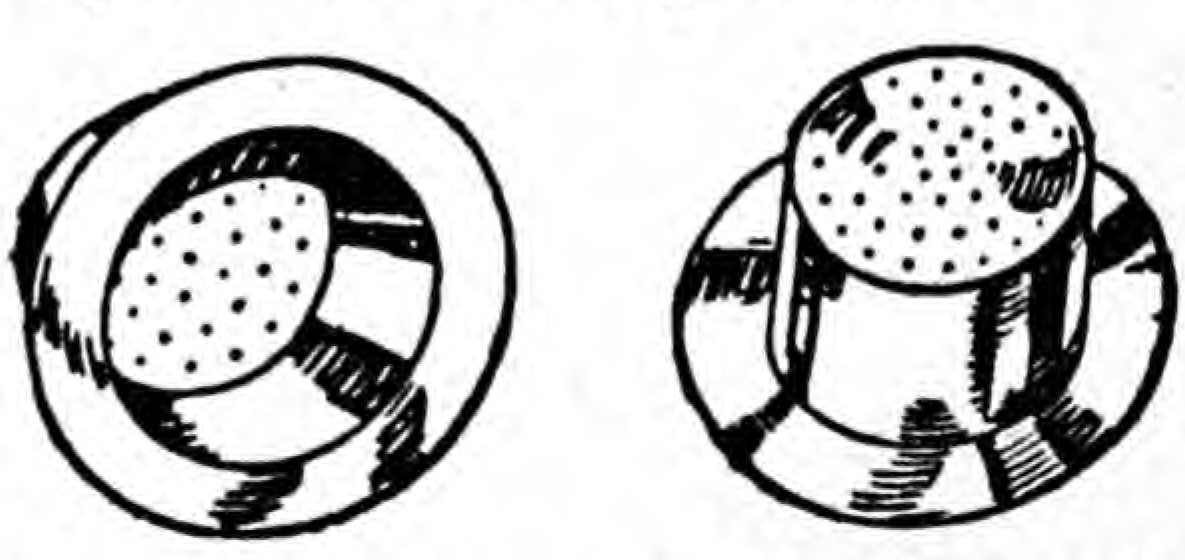


Fig. 153.—*Two views of a jet for spinning artificial silk. The thick liquid is forced through the tiny holes.*

Explosives are not, as some people think, merely terrible substances which serve for nothing but to destroy or maim human beings; they have very valuable peace-time uses, which we shall mention a little later on. Nitro-cellulose is an explosive prepared by the action of a mixture of nitric and sulphuric acid on cellulose, in the form of purified cotton. Somewhat different kinds can be produced according to the thoroughness with which the nitric acid acts on the cotton, the "degree of nitration" as the chemists call it, which depends upon the proportions of the acid mixture used. One kind is called gun-cotton, used especially for such things as blowing up bridges in war, and destroying tree stumps when clearing forests in peace-time. It is used in making various mixtures used for blasting in peace-time, but for this purpose nitroglycerine is more important. This is *not* a carbohydrate, but as we are talking of explosives we will say a word about it.

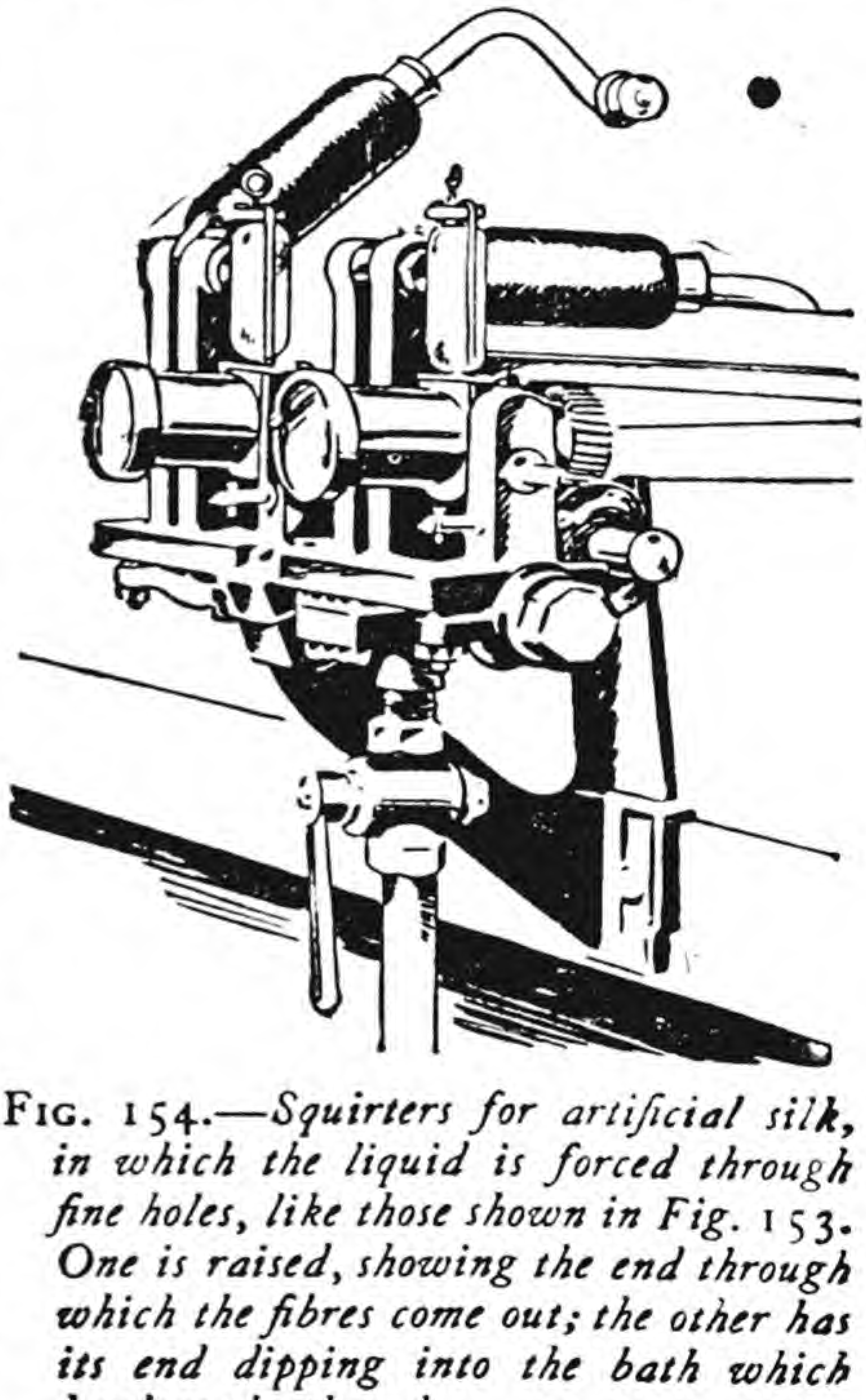


FIG. 154.—*Squirters for artificial silk, in which the liquid is forced through fine holes, like those shown in Fig. 153. One is raised, showing the end through which the fibres come out; the other has its end dipping into the bath which hardens the threads.*

Nitroglycerine is made from glycerine, which, as most people know, is a very thick, sticky, sweet liquid prepared

from fats. The glycerine is treated with a mixture of nitric and sulphuric acid, and an oily liquid is obtained, which is a dangerous explosive, as it goes off very easily—for instance, by violent jolting. At one time the liquid itself was used in mining and suchlike jobs, and caused several bad accidents. Alfred Nobel then discovered that if the liquid nitroglycerine was soaked up in some spongy or sandy material, such as powdered charcoal, a solid explosive would be produced which could be safely handled. The solid actually used is a kind of fine, dry, powdery earth

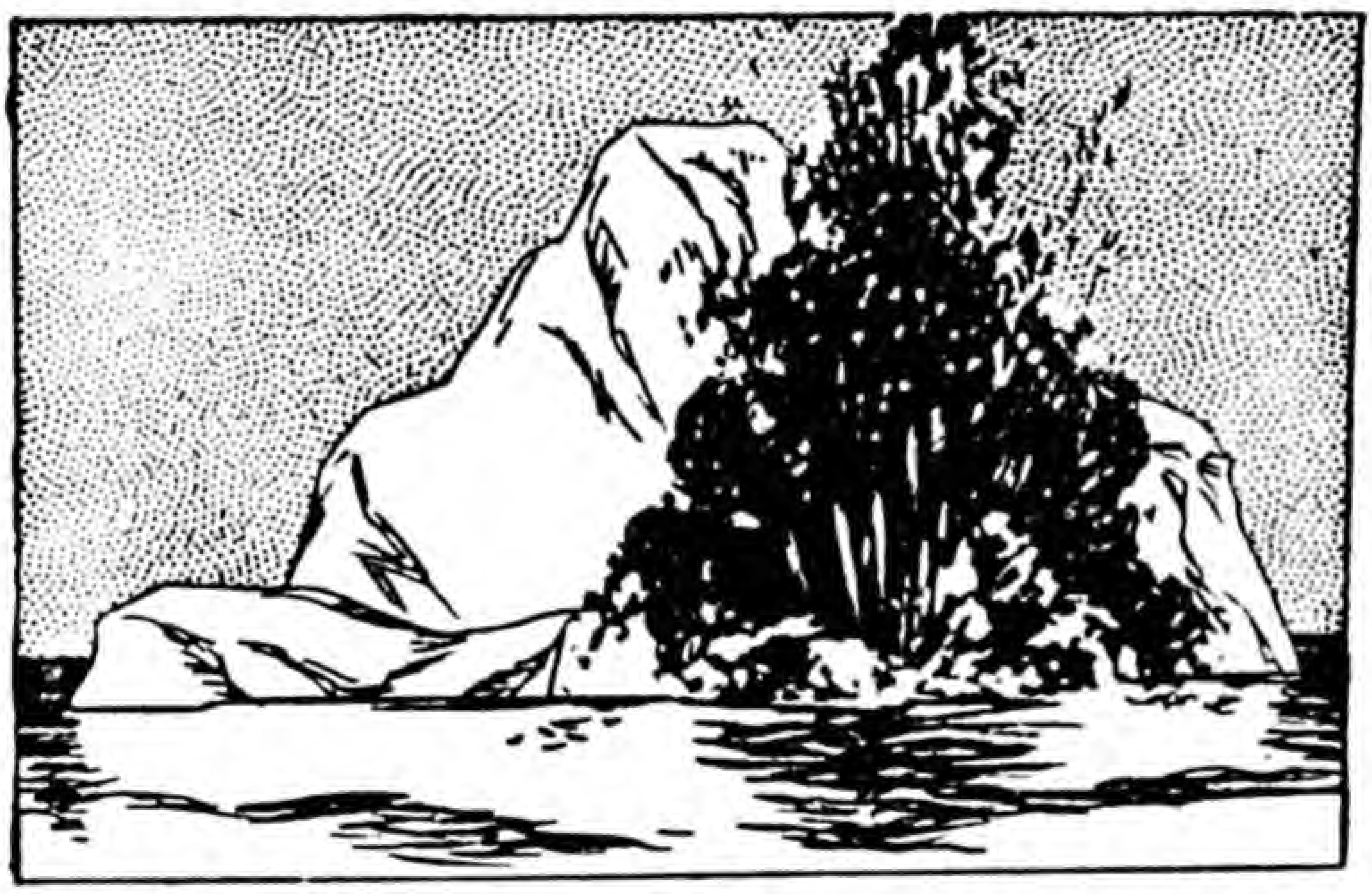


FIG. 155.—*The peaceful use for high explosives: breaking up an iceberg, which is floating in the steamship lanes.*

called kieselguhr, and the explosive produced is called dynamite. It can be carted about and jolted with comparative safety. Many other explosives for blasting are made with nitroglycerine, sometimes mixed with nitrocellulose. "Blasting gelatine," for instance, consists of about 90 per cent. of nitroglycerine, 9 per cent. of nitrocellulose, and a little chalk.

By "blasting" is meant the shattering of rocks and earth by explosives, either, for instance, in mining or in making canals and suchlike. About 15 thousand tons

of explosives are used every year in connection with mining and quarrying in Great Britain alone, which gives some idea of the extent to which we depend on them. An undertaking like the Panama Canal, to make which 175 million cubic yards of rock and earth had to be cleared away, would have been impossible without the use of blasting explosives. Roughly speaking, one pound of explosive can break up one ton of rock. There are many other explosives made from organic chemicals, besides nitrocellulose and nitroglycerine—for example, trinitrotoluene (called T.N.T., from the initial letters of tri, nitro, and toluene), prepared from the substance toluene which is mentioned in the next chapter. There are also inorganic explosives, such as ordinary gunpowder.

Cellulose acetate, a compound made from cellulose and acetic acid, can be dissolved in amyl-acetate (a solvent which smells like pear-drops). After various gums and resins have been added it is used as a varnish or "finish" for motor-cars, and is sprayed on with an instrument something like a scent-spray.

Cellulose, then, is a very important stuff. We use it for food, for paper, for clothing, for mining and making canals, for varnishes and for many other purposes which have not been mentioned, such as artificial leather, celluloid and, what some people will think the most important use, the film for moving pictures. It is, then, easy to understand how it happens that many very clever people spend their lives studying the chemistry of cellulose, in the hope of inventing new sorts of fibres. varnishes, and explosives.

CHAPTER VII

ORGANIC CHEMISTRY: ALCOHOL AND COAL TAR

Alcohol and Fermentation—Coal and Its Products: Benzene

Alcohol and Fermentation

WE have already often had occasion to speak of that common substance, methylated spirit, and have said that it consists of ethyl alcohol with small quantities of other substances added to give it a taste so nasty that people will not drink it. Ethyl alcohol is often called just alcohol, since it is the commonest kind of alcohol, but there is a whole series of alcohols, of different chemical composition, just as there is a whole series of paraffins. The simplest kind—that is, the kind for which the molecule has the fewest atoms—is called methyl alcohol; the next is the ethyl alcohol we have just mentioned; then comes propyl alcohol, and then a whole lot more. Each one in the series has one carbon atom and two hydrogen atoms more than the one before, just as each paraffin in the series of paraffins has one carbon atom and two hydrogen atoms more than the one before it. What all the alcohols have the same, and what makes them different from the paraffins, is an oxygen and a hydrogen atom stuck together—an OH group as the chemists say. This is the feature of their structure that makes them all behave chemically in the same sort of way—the family likeness, so to speak.

To make an alcohol with our model atoms we want a model of the oxygen atom, which we must provide with two arms, for it behaves in molecules as if it had two points of attachment. On one we stick a hydrogen atom, and we now have our OH group. If we pull the H from

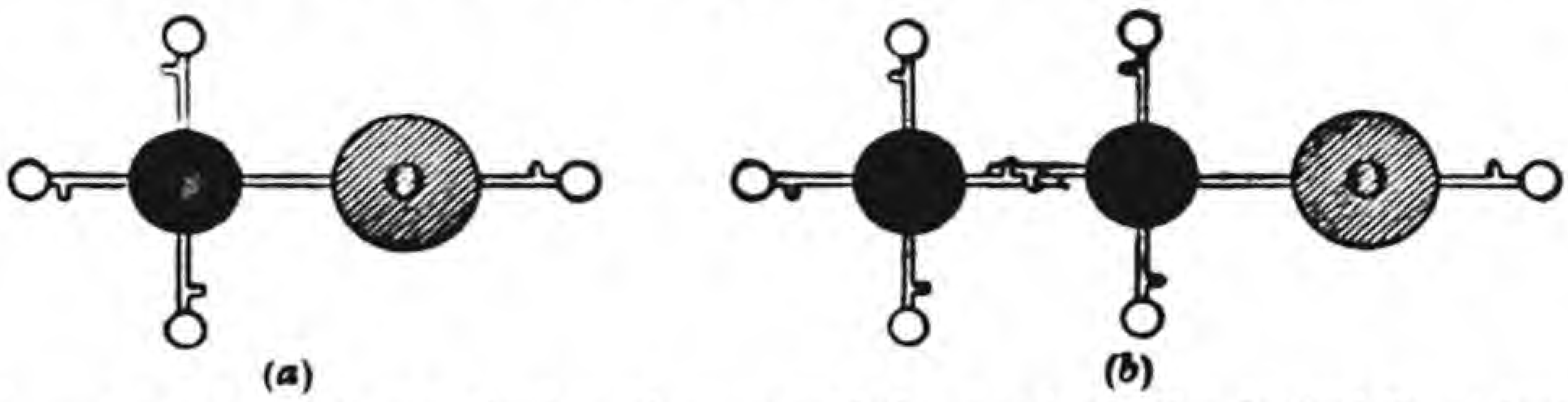


FIG. 156.—*Models of alcohol molecules: (a) methyl alcohol; (b) ethyl alcohol.*

one end of a paraffin, and replace it by the free arm of the OH group, we have a model of an alcohol molecule. If we make an alcohol out of methane it is methyl alcohol: from ethane we get ethyl alcohol, which is therefore C_2H_6O, which we can write $C_2H_5.OH$ if we want to remind ourselves of the OH group: from propane, propyl alcohol: from butane, butyl alcohol, and so on. You see how simple the "families" make it to remember how the molecule of a particular organic compound is made up.

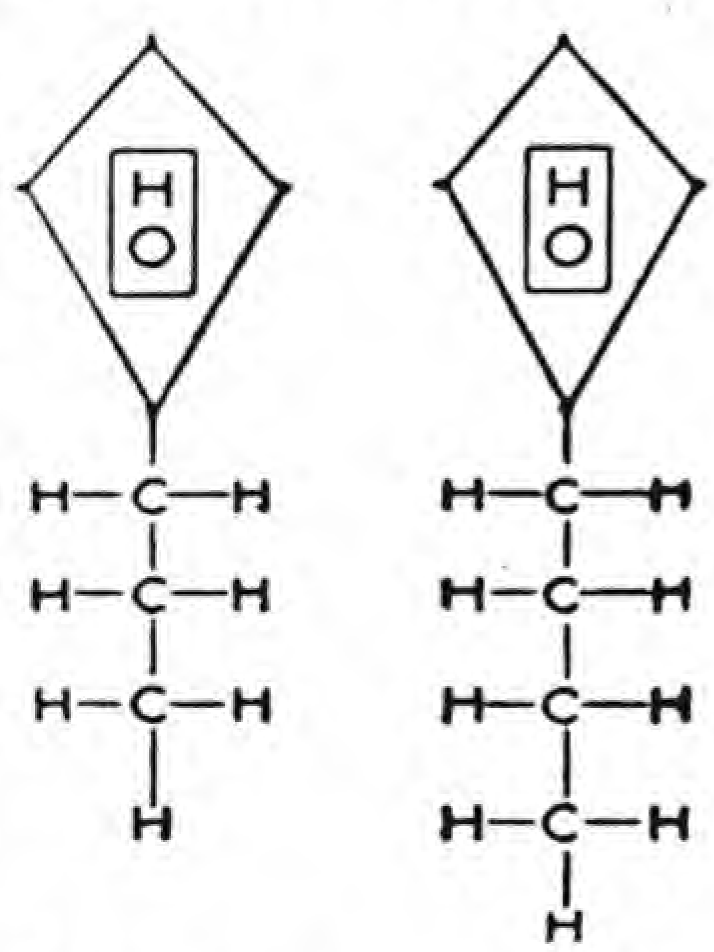


FIG. 157.—*Alcohols as kites.*

We can, to help our memory, think of the alcohol molecules as kites. The OH is then the body of the kite, and the CH_2 is a bit of paper on the tail, with an H on the end to finish it off, as shown in Fig. 157. Some kites have long tails, some short; they differ only in the number of bits of H-C-H paper tied on to the string of the tail. The chemist, who has special methods of dis-

covering groups of atoms by their chemical behaviour, recognises an alcohol by the OH group. Series of substances, like the series of paraffins and the series of alcohols which we have considered, with one particular feature of the arrangement that makes all of a series have the same kind of chemical properties, occur all through organic, but not in inorganic chemistry.

We will talk of ethyl alcohol, as it is by far the best known and the most important of the alcohols for ordinary purposes. It has been prepared since the earliest historic times by fermentation, and we must now consider what fermentation means. Let us put in a flask a solution of ordinary sugar, about an ounce to the quart, and arrange for a tube leading from the flask to dip under the surface of lime-water in another flask. We take out the cork, add a little fresh brewer's yeast (of which we spoke in Chapter VII of Book I), put back the cork, and leave the solution to stand. After a time bubbles of gas will appear in the flask, and force their way through the lime-water, which will turn milky, showing that the gas is CO_2. The yeast must therefore be acting on the dissolved sugar, since the carbon in the CO_2 certainly cannot come from the water. The lime-water flask is closed by a cork, through which passes the tube from the first flask and also an escape tube full of pieces of caustic potash, to prevent any CO_2 from the air getting at the lime-water.

Having left the whole apparatus standing some time, say overnight, to give the yeast a good chance of doing its work, we take some of the liquid from the flask, and proceed to carry out one of the commonest jobs of the organic chemist, namely distillation.[1] We have already

[1] The liquid, as taken from the flask, will only contain about 1 per cent. of alcohol.

spoken of the distillation of water, and industrial distillation of such things as petroleum. In the laboratory it is widely used as a way of separating two liquids which boil at different temperatures, and is carried out as follows. The flask is joined to a long tube which is cooled by water running into a surrounding tube at the lower end, and out at the higher. The tube slopes downwards a little, so that any liquid drops formed inside it run down into the receiving flask C, and not back into the boiling flask A. If what is in this flask A is a mixture of two

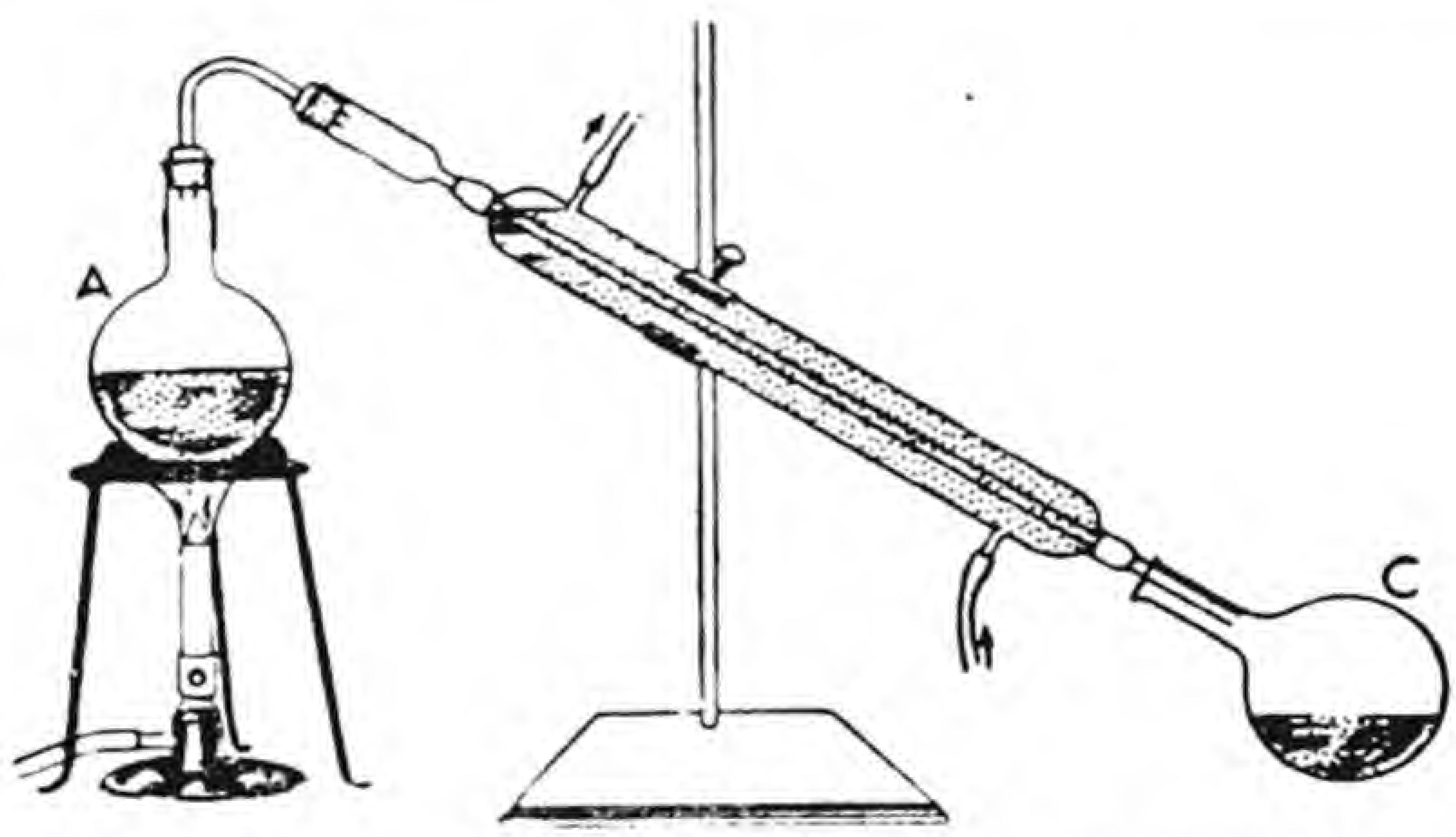


FIG. 158.—*Apparatus for distilling organic chemicals.*

liquids, the one that boils at the lower temperature will turn into vapour most readily, and this vapour will come off, condense again in the cold tube, and run down into the flask. Of course, some vapour from the other liquid will come over too, but not as much, as it is more difficult to boil. The liquid which we collect in C will still be a mixture, but much richer in the easily boiling liquid than that in the flask A. If we now take the liquid which has distilled over, put it in a flask like A, and distil again, what we collect this time will be richer still in the easily

boiling liquid. If we repeat the process a few times we can get the liquid practically pure.

We distil, then, the liquid left behind in our sugar-and-yeast flask, and let the liquid which comes over stand with quicklime in it for some hours, which further helps to take out the water. We then distil again, and collect in the receiving flask a colourless liquid with a pleasant sweetish smell. A little of it may be placed on a dish and lit, when it will burn with a colourless flame. It dissolves camphor or rosin, and also dissolves varnishes and polishes, as may easily be seen by dropping a spot on a rough piece of varnished wood—not valuable furniture, of course. It is alcohol. A chemist would make more certain by finding the boiling-point, which is 78° C., and the density, which is .79 grammes per cubic centimetre for pure ethyl alcohol, and we can do so too, if we have time.

We see, then, that the action of yeast on a weak solution of sugar is to turn the sugar into alcohol, the gas carbon dioxide being given off in the process. This is the commonest example of the process that is called fermentation, and the only one that most people know of, but the word fermentation is used for many other chemical processes which are started and kept going by fungi or bacteria[1] (see Book I). The formation of carbon dioxide means that some of the carbon has to be removed from the sugar if it is to become alcohol. It used to be

[1] Some people use the word "fermentation" for any kind of chemical action in which yeasts or moulds or bacteria play an important part, while others prefer to keep the word for those processes in which sugars are turned into alcohol and carbon dioxide, and to speak of "enzyme action" (see p. 241) in the case of the others. This is just a question of words, and does not matter much so long as we are clear as to what happens.

thought that living yeast cells were necessary to produce fermentation, but it has been found out that substances can be extracted from the killed yeast which will have the same effect in producing fermentation as the living yeast itself will. These substances are called *enzymes*, and they are exceedingly important, because there are many kinds of fermentation which are used to-day in industry, and each requires its special enzyme to produce it. For instance, vinegar is made from alcohol by the help of the enzyme from a tiny organism, called *mycoderma aceti*, which is put into the alcohol, and citric acid is made from sugar by another enzyme. Very little of an enzyme produced by the yeast or other organism is required to keep a fermentation going: nothing from the enzyme appears in the final product, but its presence helps the action along. It is like a man who does no work himself, but by cheering them on and encouraging them enables men to keep going at a job which, without him, they could not do at all.

A very common use of fermentation is in the making of bread. The yeast which is added to the dough causes the small amount of sugar present in the flour to ferment. A little alcohol is formed, but only very little. The bubbles of carbon dioxide which are formed blow up the dough, and make it light, and it is for the sake of this action that the yeast is added. Bread made without yeast would be a heavy, close lump.

A great deal of alcohol is made from grain, which contains very little sugar, but a lot of starch. Just as sugar can be changed into alcohol by a fermentation, so can starch be converted into sugar by another kind of enzyme action. In making beer, for instance, barley is used. In the barley are enzymes made by the living plant

which, when the seed sprouts naturally, turn the carbohydrates which are stored in the form of starch into a kind of sugar, which can be used by the young plant in its growth. For brewing, this change is brought about by steeping the barley in water, which makes it sprout; when enough starch has been turned into sugar by the enzymes the grain is dried, and is then called malt. It has a very sweet taste, owing to the sugar present. To turn the malt into beer it is boiled with water, and yeast is added to the liquid after it has cooled, which produces fermentation and turns the sugar of the malt into alcohol. The hops which are put in during the process are only a flavouring, and it is not correct to say, as so many people do, that beer is made of hops, any more than you would say that a stew is made of salt and pepper. The formation of the malt sugar from grain, and the fermentation of the malt sugar, are the chief parts of the process.

Enzyme actions are very important in our own life. For instance, we digest our food with the aid of enzymes which our bodies manufacture. Among the enzymes are some, like that made by the salivary glands in our mouth, which turn starch into sugar, much as does the enzyme in sprouting barley. If a piece of bread is chewed for a long time it will be found to become quite sweet.

Industrial alcohol, or methylated spirits, is widely used in making varnishes, polishes and suchlike, photographic films and hundreds of other substances. Four million gallons of alcohol are turned to industrial uses in England every year. To make this from barley or other grain would be far too expensive: most of it is prepared from molasses,[1] a syrup obtained from raw sugar in the

[1] Shipped from Cuba.

process of purifying. In Germany, starch obtained from potatoes is the main source from which industrial alcohol is made. Other starchy substances, such as rice, are often used for the manufacture of alcohol.

You may have noticed that in our experiment on fermenting sugar we used quite a weak solution. It is a remarkable fact that a strong solution of sugar will not ferment; in fact, sugar, added in quantity, prevents fermentation and acts as a preservative. Condensed milk generally contains large quantities of sugar for this purpose. Again, thin wine easily turns to vinegar, but stronger wine does not: pure alcohol, and not sugar, is the preservative. All fermentation requires plenty of water, and alcoholic fermentation only goes on if the liquor turns blue litmus red—that is, if the liquor is acid.

Fermentation and distillation are two of the oldest chemical processes in use. Wine has been made from the earliest historic times, and all the famous books of olden times mention it freely. In the Bible, and in the great works of the old Greek poet Homer, we find it at all feasts, and beer was known to the ancient Egyptians. The "bloom" on the skin of the grape contains a kind of yeast which furnishes the enzyme necessary to turn the grape-sugar into alcohol, so that it is only necessary to press out the grape-juice and store it for fermentation to take place. Needless to say, the making of a fine wine is not quite so simple as this. Distillation was also used in very early times to prepare strong alcohol. A very good example of the process, which is used in modern times, is the preparation of brandy from wine. Brandy is about half alcohol, by volume, and is made by distilling wines which contain about 7 per cent. of alcohol. One distillation is sufficient. This is carried out with great

care in stills of pure copper, consisting of a boiler, A; a head, as it is called, B; and a condenser, C, which is a spiral copper pipe kept cool with water, like that in

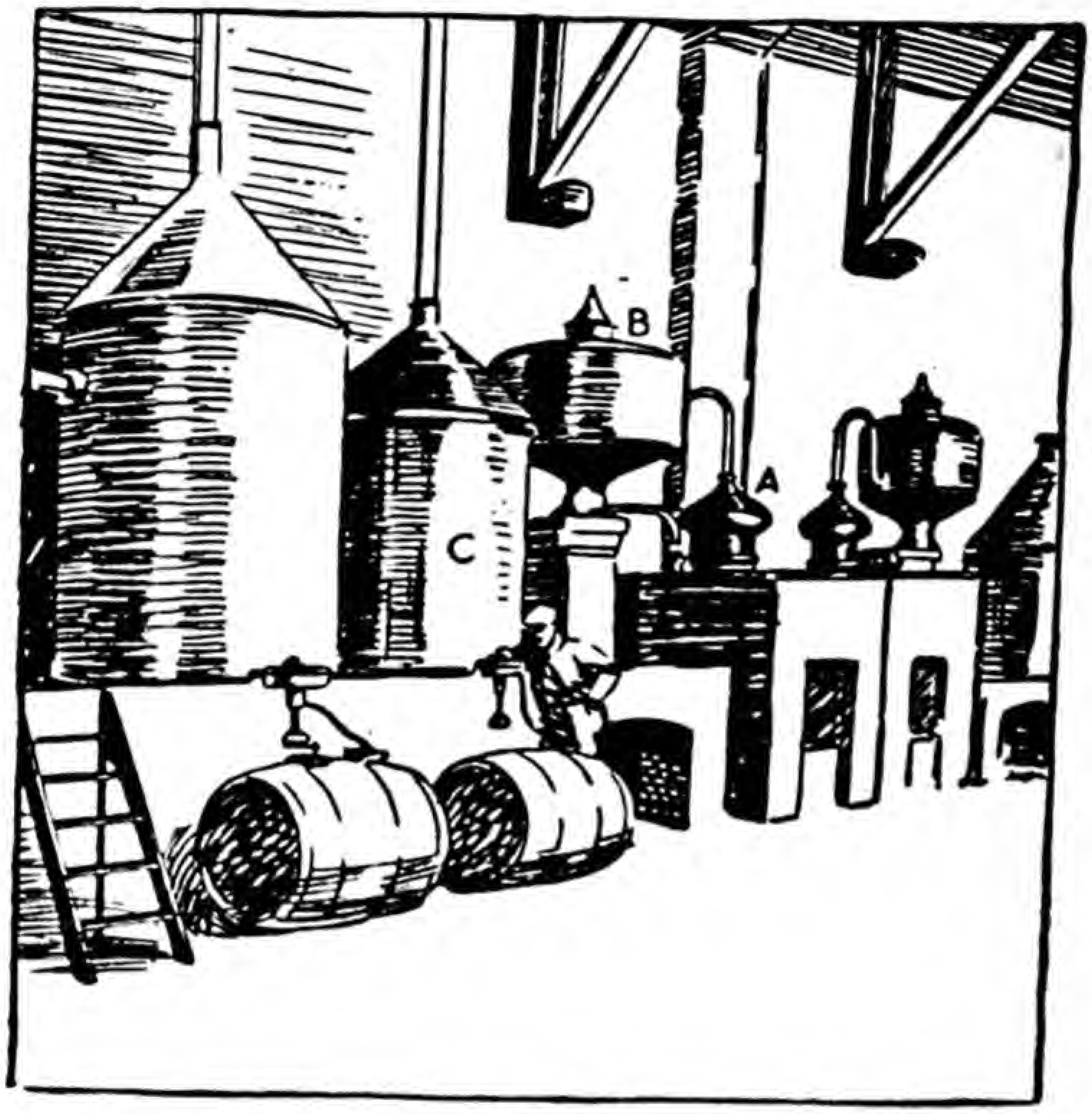


FIG. 159.—*Distilling brandy.*

Fig. 95 of Book I. The head is to hold back the vapours which condense most easily, as they would weaken the brandy.

COAL AND ITS PRODUCTS: BENZENE

We have already mentioned more than once how the gas which is supplied to houses and factories for lighting and heating is made from coal. The other things which are obtained by chemistry from coal are so important in organic chemistry and in industry, that we will now consider the making of gas rather more carefully.

The gas retorts are long tubes of fireclay, which, in a modern gas works, are arranged in rows and filled with coal by a machine travelling on rails, as shown in Fig. 160. The result of strong heating on such a retort is not only

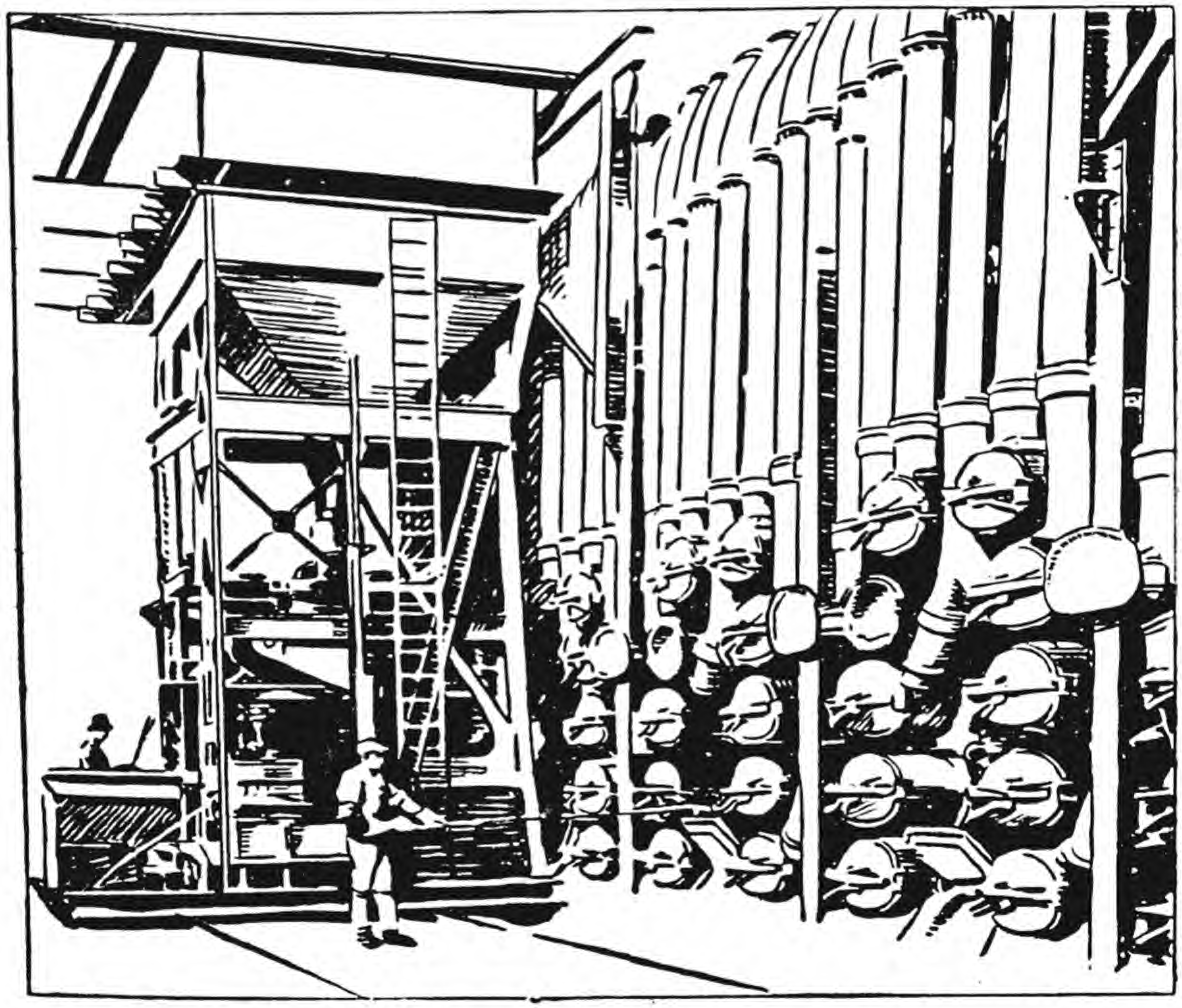


FIG. 160.—*Gas retorts.*

to produce coal gas from the coal, but also coal tar and ammonia in the form of vapour, as well as some gases containing sulphur, which, if burnt with the gas, would form sulphur dioxide, which is injurious both to health and to curtains, leather, and suchlike. If sulphur dioxide

were allowed to escape into the atmosphere in large quantities it would dissolve in the rain, forming an acid which would damage buildings, and especially metal structures such as iron roofs, and certain kinds of building stone. The object of the Gas Company is, then, to separate the tar and the ammonia, and to remove the sulphur.

The mixed gases and vapours from the various retorts pass first of all into a wide tube, called the tar main, where some of the tar condenses, and thence into a wide gas main (Fig. 161). From this they are led into tall tubes,

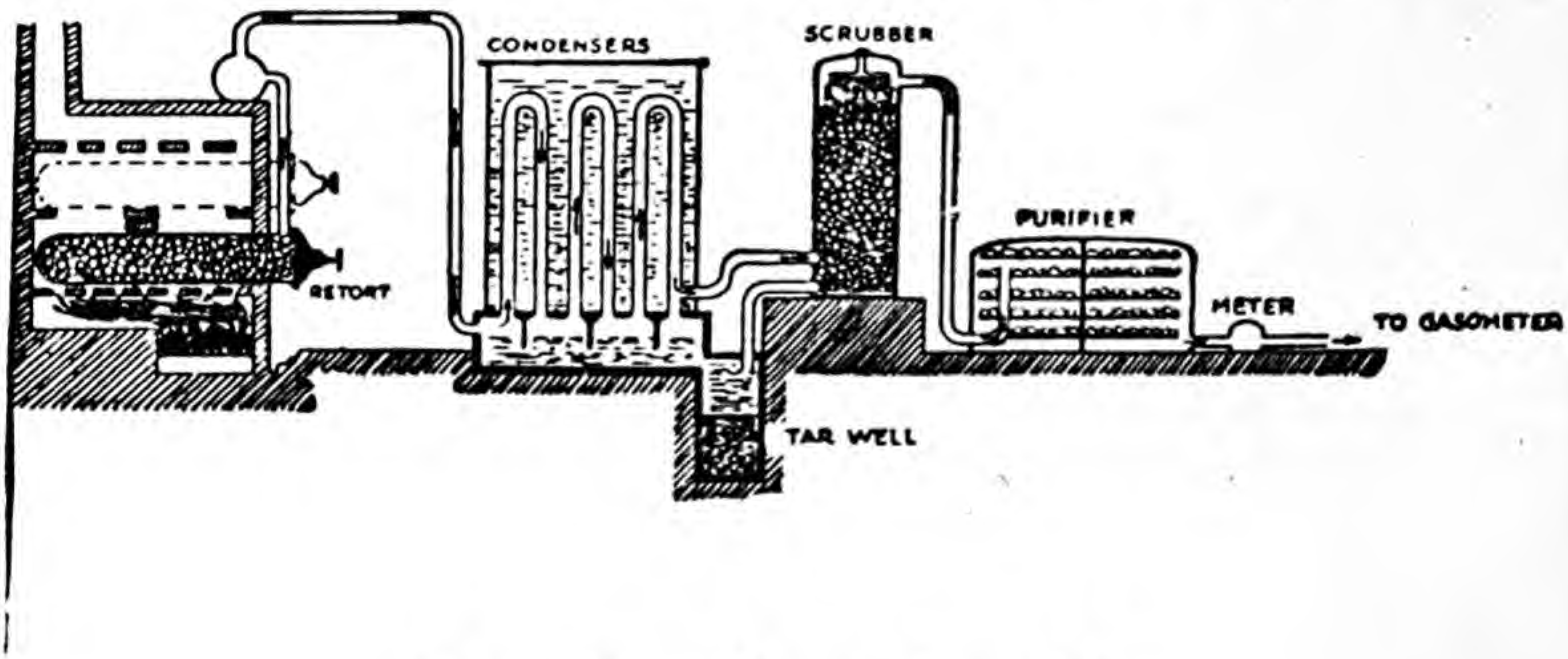


FIG. 161.—*How gas is purified.*

cooled by surrounding water, in which most of the tar condenses, and runs down into a well called the tar well, from the bottom of which it can be removed by pipes. The gases are then led into a tower, called a "scrubber," where they are washed, or "scrubbed," by being exposed to water: the water trickles over coke or metal rings with which the tower is filled, so as to provide a large surface, and give the liquid every chance to dissolve the ammonia, which is very soluble, out of the gas. The water containing the ammonia trickles into the tar well, where it does

not mix with the tar, but lies on top, so that it can be pumped off separately. The gas then enters the purifier, where the sulphur gases are removed by suitable chemicals. The gas is then ready to be burnt, and travels through the Company's big meters, to measure how much has been produced, into the gas-holders, from which it passes through pipes to houses and factories.

The gas-holders are familiar to everybody who has lived in or near a town, on account of their great size. Their construction is rather interesting. The older kind is shown in Fig. 162, both as it appears to the view and also cut through, to explain its working. It consists of a wide container, like an ordinary tumbler upside down, the sides of which are built in sections, so that they slide in one another like the parts of a telescope. The edge of the lowest section dips into water in a large tank sunk in the ground, the tank being just large enough and deep enough to take the whole of one section. The water prevents any escape of the gas. When the gas-holder is pumped full the sections are fully extended, as shown in Fig. 162, and the weight of the holder keeps the gas under sufficient pressure for supply purposes. As the gas is used up, the top, which is kept steady by guides, descends, telescoping first the lowest section, and then the other sections, until nearly all the gas is driven out. Then the holder is pumped full again. Special devices are used to seal the joint where one section slides into the other.

The newer kind of gas-holders are built much larger, and are called dry gas-holders, as there is no water tank. The way in which these holders work is very simple, for they consist simply of an immense tube, the top of which slides down and pushes the gas out. As the sides do not

move you cannot see from outside how full the holder is, as you can with the older kind. You may wonder why,

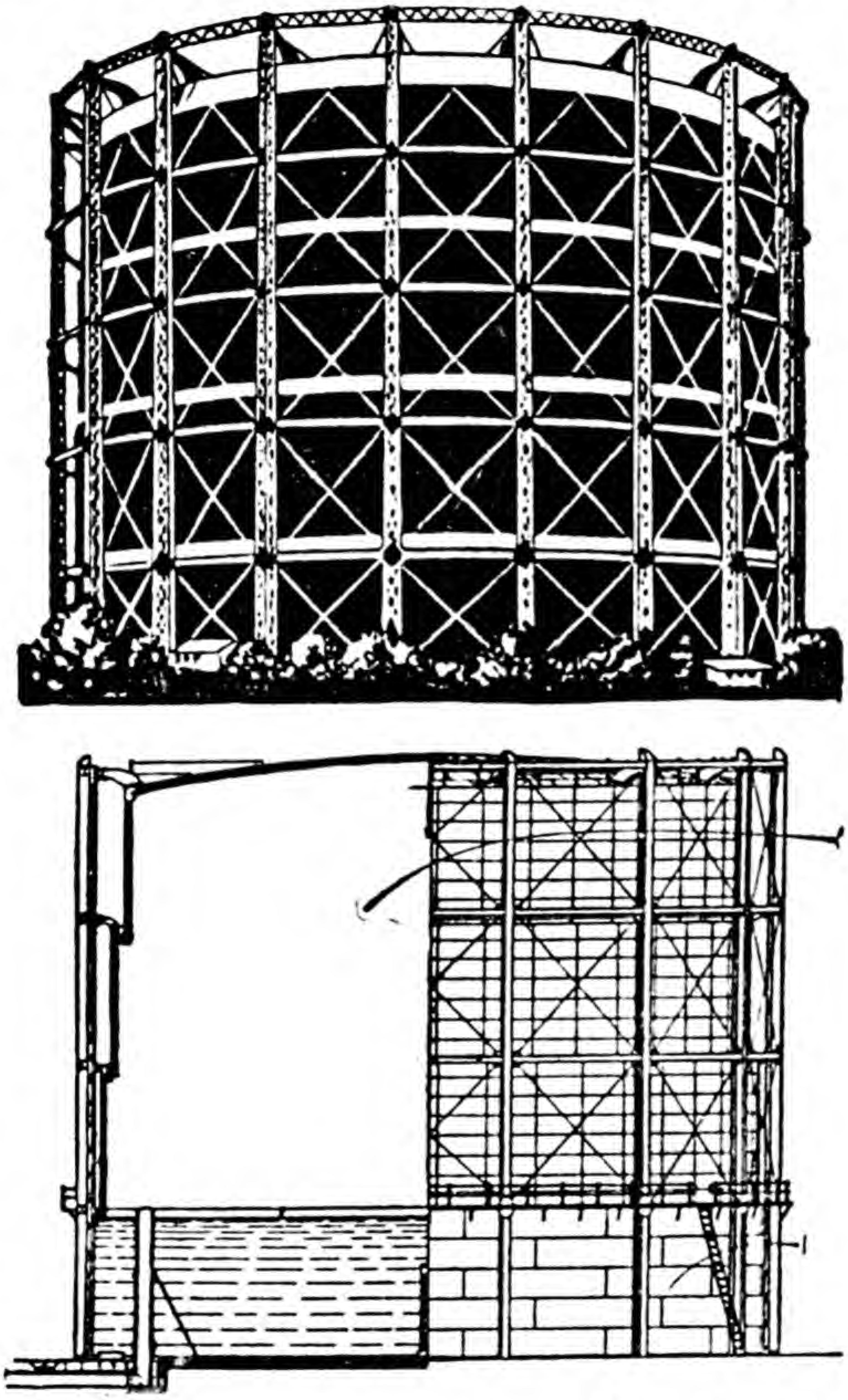


FIG. 162.—*Telescope gas-holder: above, outside view; below, section, to show how it works.*

since the principle is so simple, holders of this kind were not made long ago. The reason is that it was found very difficult to make the joint, where the roof touches the

sides as it slides down, gas-tight, and it is only of recent years that a way of using gas tar to seal the joint has been found. In another kind of dry gas-holder rubber rings are used to keep the gas in.

Everyone has some idea of what happens to the gas after it leaves the holder—how it is used for heating in factory furnaces, for cooking, for heating houses, and for lighting. Let us go back and see what happens to the things removed from the gas in the course of purification.

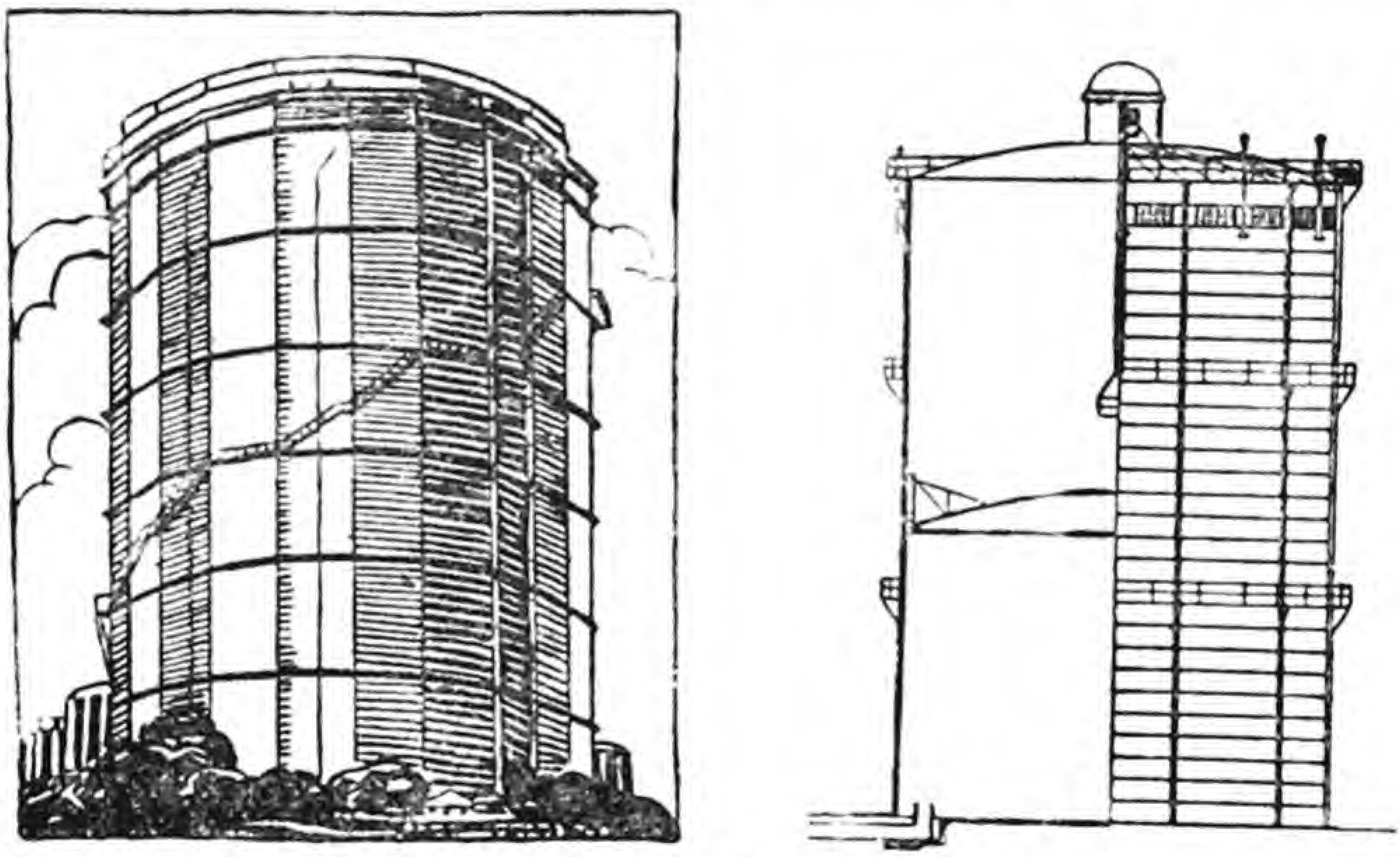
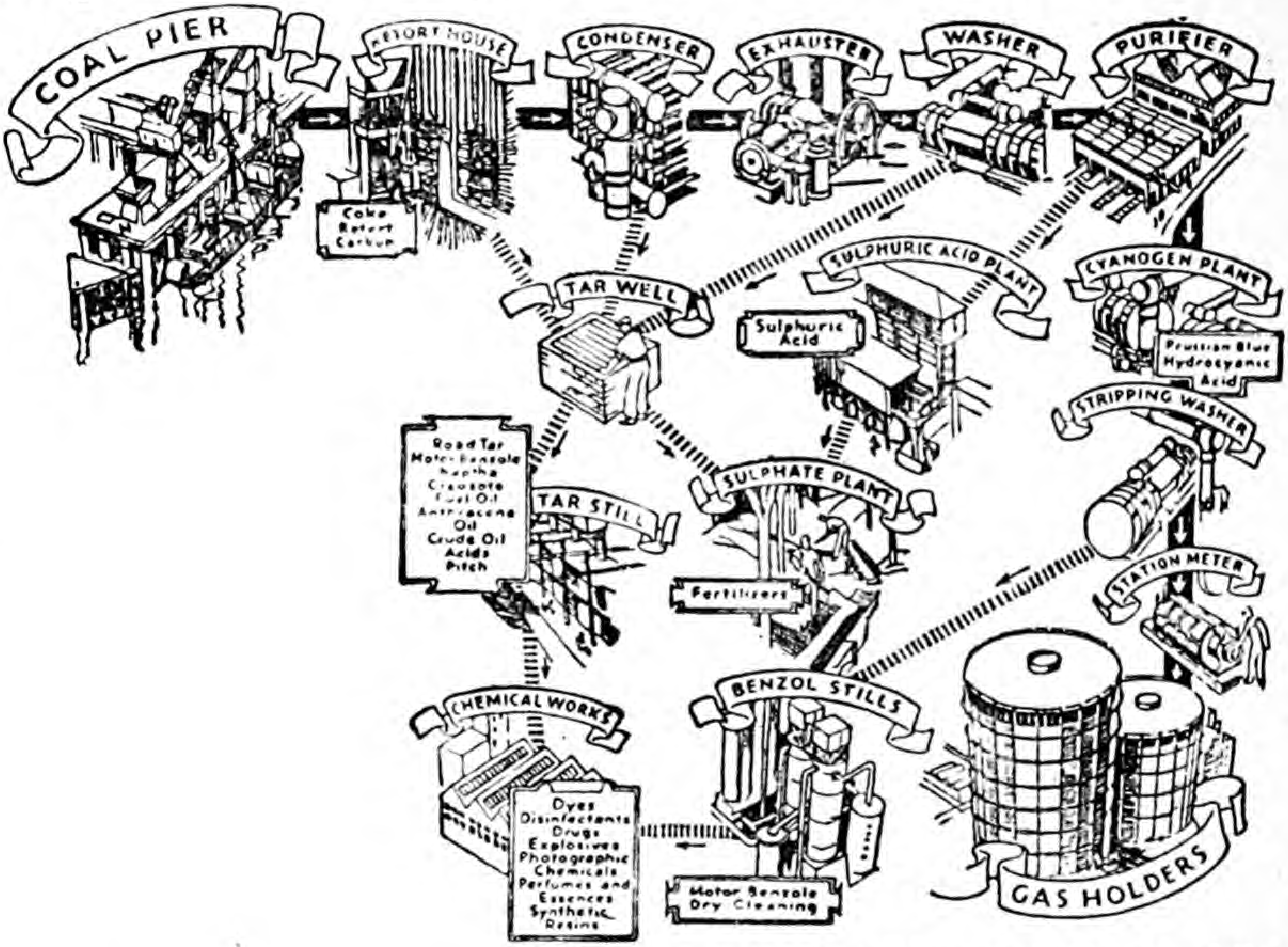


FIG. 163.—*Dry gas-holder. On left, outside view; on right, section.*

The ammonia is boiled out of the ammonia liquor and then combined with sulphuric acid to make ammonium sulphate, which is a white, crystalline solid substance used as a fertiliser. This kind of substance is called an artificial manure. The substance left in the retorts is coke, which is so widely used as a fuel. It has the great advantage that it makes no smoke, and when we burn it we do not waste the coal tar and ammonia which are in coal. A specially hard kind of coke, called retort carbon, gradually collects

on the walls of the retort, and is used for making "carbons" for electric arc lamps and other things, even pencil leads.

The coal tar, the thick black sticky stuff that is condensed from the coal vapours, is a very remarkable substance, which is a mixture of many different chemical compounds, just as petroleum is. It is distilled in four



(*By courtesy of the British Commercial Gas Association.*

FIG. 164.—*A quick view of the processes by which gas and by-products are made from coal.*

stages, and the stuffs that come over, starting with the low temperature and going to the high one, are called light oil, middle oil, heavy oil, and refined tar. About 70 per cent. of the whole is left behind in the retort and this is the substance which you know as pitch, used for tarring roads, for roofing felt and suchlike purposes.

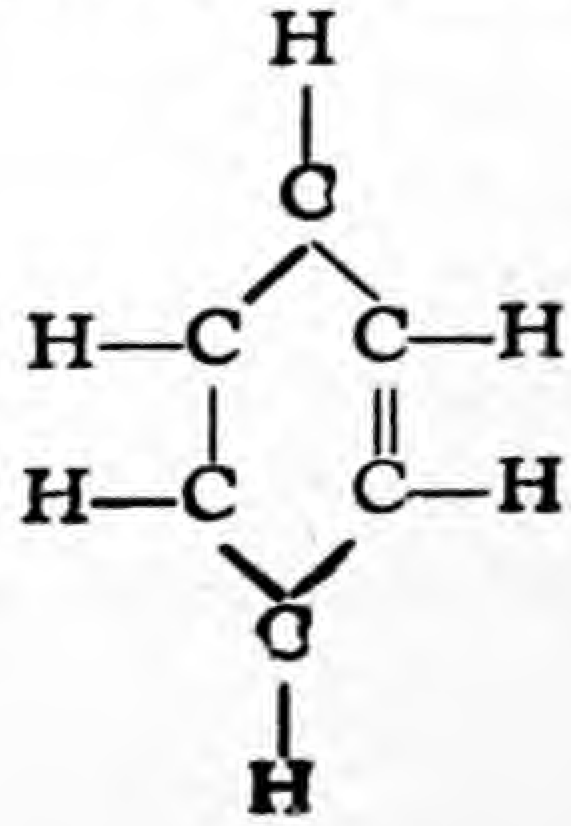
From the other 30 per cent. are prepared a whole series of organic chemicals of the highest importance, from which disinfectants, antiseptics, flavourings, and wonderful dye-stuffs are made. These organic chemicals prepared from coal tar are quite different from the paraffins, the alcohols, the sugars, and all the others which we have talked of up to now. The chief of them are benzene, toluene, xylene, phenol, cresol, naphthalene, anthracene, pyridine, thiophene, and many more. There is no need to learn the names of all these substances : they are put down here so that, in case you hear any of them, you may happen to remember that they come from coal tar. One or two of them, however, you are pretty sure to know under other names. Phenol is the disinfectant usually called carbolic acid, or just carbolic, while naphthalene is the white, crystalline-looking stuff with a powerful smell, of which "moth-balls" are made.

The simplest and in some ways the most important of these substances is benzene; this is quite a different thing from benzine, which, as we have said, is the name given to a mixture of paraffins something like petrol. The liquid called benzol is impure commercial benzene. Benzene is a clear, thin liquid with a distinctive smell, which boils at 80° C. It burns easily with a very smoky flame, which suggests to us that it is rich in carbon. It does not mix with water, but it dissolves fats, oils, grease, resins, and many other substances which do not dissolve in water. For this reason it is much used for cleaning clothes in "dry cleaning."

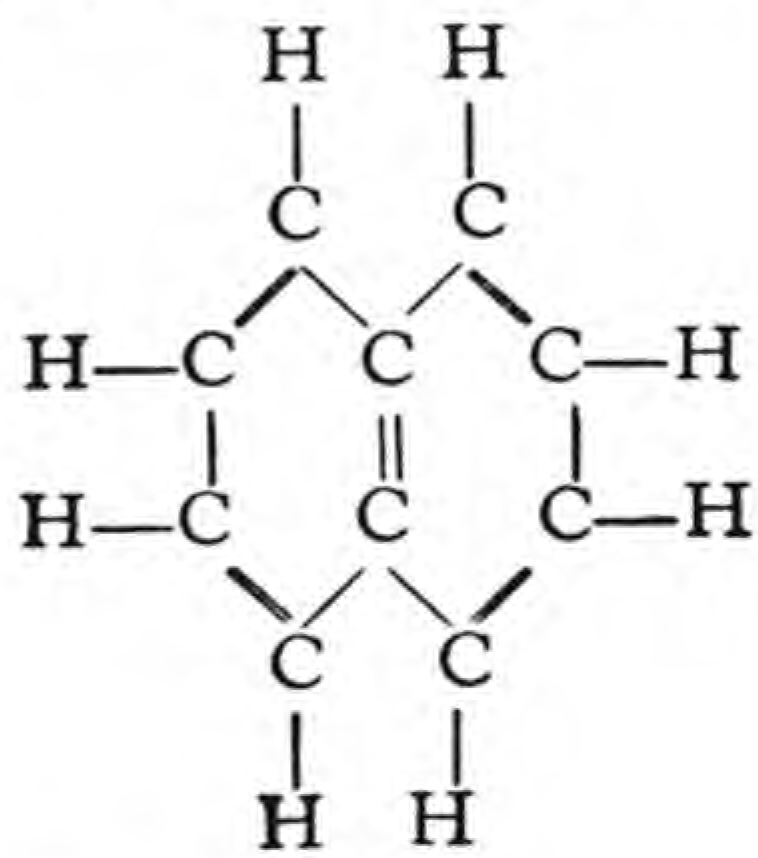
Benzene was discovered by Faraday in 1825; for a long time it was of interest only to men of science, and had no practical use. In 1856, however, Sir W. H. Perkin, who was then a boy of eighteen, prepared the

first dye to be made from coal tar, namely mauve. The story of the way in which, before the War, the whole industry of making dyes from coal tar was allowed to pass from this country into German hands, is a sad one for us. Since the War, however, much has been done in the way of making dyes from coal tar in England. To-day something like 15,000 tons of dye-stuffs are made from coal tar every year in Great Britain, which seems an enormous quantity until we learn that the production in the whole world is 165,000 tons per year. Remember that a ship that will carry 10,000 tons is a large vessel, and you will get some idea of the amount of dyes that are made by the method of organic chemistry.

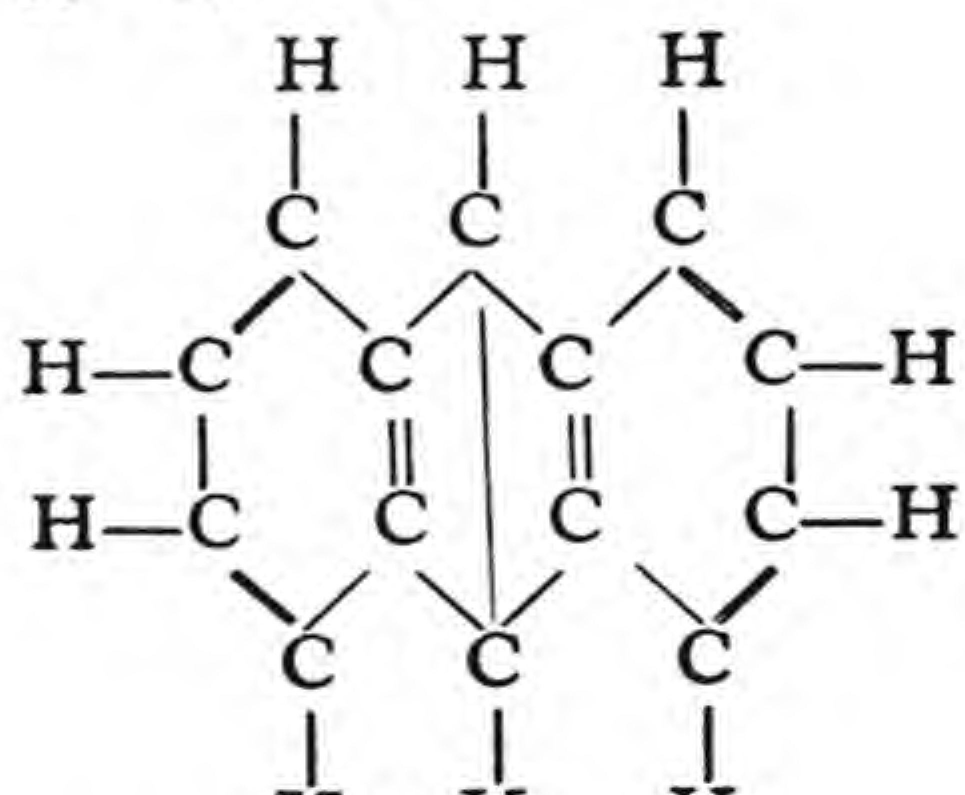
Benzene is C_6H_6, six atoms of carbon and six of hydrogen. From the chemist's point of view the remarkable thing is that the carbons are not arranged in a line, but in a ring of six. If we make a model with our carbon balls, as before, we shall be left with an arm over on each carbon atom, since each carbon has four arms, of which one goes to a hydrogen, and two more to hold on to the next carbon atom on each side. For reasons that are rather too difficult to give here, it is best to join the odd arm to one of the neighbouring carbon atoms, so that, in the ring of six, three are joined by double arms (or bonds as they are called) and three by single bonds, as shown. Each carbon then has four bonds.



The six carbons are usually written in this way, in the form of a six-sided figure, or hexagon, but chemists always speak of the benzene ring. In all the chemical substances we talked of earlier the carbons were in some kind of a line, sometimes bent, it is true, but always open at each end, an open chain as the chemists say. Not only in benzene, but in nearly all the other substances which we mentioned as coming from coal tar, the carbons are arranged in one or more rings. Thus naphthalene, $C_{10}H_8$, is written thus:



and anthracene, $C_{14}H_{10}$, thus:



All the chemicals that are manufactured from coal tar are prepared by making atoms join on at the corners of such rings.

Many of the ring compounds smell fragrant and spicy, and so the whole lot are called *aromatic*, although actually some of them have no smell, and others a very unpleasant one. The open chain substances, like the paraffins, alcohols, and sugars, are called *aliphatic*, from a Greek word meaning oil or fat. These are the two great classes of organic compounds, aromatic and aliphatic. Organic chemistry is full of amusing words. Names like tetramethyldiaminobenzophenone are common.

From benzene, nitric acid, and sulphuric acid a liquor called nitrobenzene can be made, which smells like almonds. From nitrobenzene the substance called aniline is made, and from aniline a whole series of brilliant dyes can be prepared. People often call all coal tar dyes aniline dyes, but that is wrong, as many of them are made from other of the coal tar chemicals. Artificial indigo, for instance, is made from naphthalene, the substance used as moth-balls, remember. The discovery of how to make indigo in the laboratory was a great triumph for the chemists, and will give us a good example of what science can do.

Indigo is a deep blue dye used for serges, for the sailors' suits of all nations, and up to the beginning of this century it was all made from a plant which grows in India. So important was this plant that about a million acres were planted with it, and the crop was worth £4,000,000 a year. The dye fetched from eight to twelve shillings a pound. Then the Germans found how to make it from naphthalene, and could sell it for less than a shilling a pound. It must be made clear that the indigo made from naphthalene is not an imitation of that made from plants, but is the same chemical substance.

There is a very interesting story concerned with the

discovery of how to make indigo. One stage in the process could not be made to take place fast enough: the chemical action did occur, but so slowly that it was no good for commercial purposes. One day a thermometer was broken accidentally in the mixed chemicals, and suddenly the reaction began to go in the way required. We know now that the presence of mercury is necessary to make the reaction really go, and this is how it was found out by accident. A good many thermometers have, however, been broken in schools without anything being found out except that glass is brittle, which is not a new discovery. This action of mercury is another example of the behaviour which we spoke of in connection with enzymes: the substance has to be there, but it is not used up in the course of the reaction. Its mere presence is sufficient to make the reaction go on. There are hundreds of processes that need an encourager of this kind, which is called a *catalyst*, and its action *catalysis*. Thus, if there were a lot of boys wanting to play a game of football, but they could not decide about sides, and so on, and a master came on the field, and organised a game, but merely watched and did not play himself, you could say that he acted as a catalyst, or catalysed the game. A very important job in chemistry is to find the right catalyst for certain reactions. In the making of margarine, for instance, finely divided metal nickel is mixed with liquid oil at one stage of the process to help it to combine with hydrogen forced in under pressure, which hardens it. There is, however, absolutely no nickel present in the finished margarine, any more than there is mercury in the finished indigo.

The most precious dye in olden times was Tyrian purple, made from a shell-fish called the Murex. It was

so rare that it was reserved for emperors and their families. A few years ago it was discovered how to make exactly the same dye from coal tar, so that to-day anyone, for a few shillings, can wear a scarf dyed with the royal purple. Hundreds of things besides colours can be made from coal tar. Aceto-salicylic acid, which is usually called aspirin in shops, is made from phenol: so is methyl salicylate or "oil of wintergreen," much used, under many different names, as an embrocation for rheumatism. Flavourings of many kinds, new anæsthetics and explosives and scents, are further products of the coal tar industry.

QUESTIONS AND EXERCISES

CHAPTER I

1. Pick out, in Figs. 1 and 5, and describe, anything that suggests a use of electricity.

2. What is a pylon? What would you expect to find if you followed a line of pylons to its end, first in one direction and then in the other?

3. Why is the thunder always heard after the lightning flash is seen? If the interval between the two is noted at a particular time, and found to be six seconds, and if five minutes later it is three seconds, is the storm approaching or going away?

4. What places should be avoided in a heavy thunderstorm, and why?

5. Write a short essay on animal electricity.

6. What is the difference between a conductor and a non-conductor of electricity? Show how you would arrange the battery and lamp of a pocket torch so as to test whether a piece of marble is a good conductor or not. Why cannot you use this method of test with a substance like green wood, which actually conducts, but is a poor conductor?

7. How can you show the difference between a true and an induced electric charge?

8. Make the toy described on p. 31, and write an explanation of its action.

9. Explain, with a picture, exactly how you would arrange to show that a gas flame produces an electrical effect.

CHAPTER II

1. Describe what is alike, and what is different, in an electric lamp and an electric radiator.

2. What is a rheostat? Explain with a diagram[1] how you would fix up an electric iron so that its temperature could be made less if required.

3. Show, with a diagram,[1] how you would arrange to measure which of two coils of wire produced the greater heating effect, when the same current is flowing through each of them.

4. Describe how an electro-magnet can be made out of a rod of soft iron. How would you arrange to measure what weight could be held up by a rod of soft iron touching such a magnet, (*a*) when a current of 1 ampere was passing through it, (*b*) when a current of 2 amperes was passing through it.

5. Describe two ways of showing that a current flowing through a wire produces a magnetic force near it. (See Chapter III for one of these.)

6. A pivoted magnet is arranged with a wire which can be put parallel to it, either above or below the magnet. A point of the wire near the N pole is called A, and a point near the S pole is called B. A current is now passed through the wire. Draw the position of the magnet as seen from above, marking the poles, in the following four cases:

(1) Wire above, current from A to B.
(2) Wire above, current from B to A.
(3) Wire below, current from A to B.
(4) Wire below, current from B to A.

[1] In all diagrams the symbols explained in Fig. 38 may be used.

7. Describe the use of a hydrometer in testing electric accumulators, explaining the kind of change that takes place in the condition of the cell during use.

8. What are the chief differences between a dry cell and an accumulator?

9. Explain the difference between voltage, current, and power. What units are used to measure them? Fifty lamps, each of 60 watts, are put in a 240-volt D.C. (Direct Current) circuit. Find out (*a*) how much current the lamps take altogether, which will tell you what kind of a fuse is required; (*b*) how much the lamps will cost to run per hour, supposing that electricity costs 2d. a B.T. unit.

10. Describe the purpose of an electric fuse. Suppose that in a house, where a fuse has blown, no fuse wire can be found and somebody suggests using a hairpin. What can be said for and against the proposal?

CHAPTER III

1. How can you show that in any magnet the north and the south poles are of equal strength? Two equal magnets are fixed in the form of a cross. What do you think will happen if the cross is floated? Try it.

2. How can you show the lines of force round a magnet? How could you use a very small pivoted magnet to show that the line of force through any point gives the direction of the magnetic force at that point?

3. Explain the meaning of "induced magnetism," "temporary magnetism," and "permanent magnetism," and how you would arrange experiments to illustrate your answer.

4. What is the difference between geographic north and magnetic north? What is an isogonal line?

5. Why do we say that the earth behaves as if a great bar magnet were buried in it?

6. Describe some of the differences between a ship's compass and a scout's compass.

7. Explain the construction of the simplest dynamo for producing alternating current.

8. Explain under what conditions a current can induce a current in a neighbouring circuit. Describe the way in which Faraday first showed induced currents.

9. How is it that a dynamo on the axle of a train acts as a brake when we are taking current from it, but has no effect when we are not so doing?

10. Describe how, in the simplest form of electric motor, a direct current produces a turning of the armature.

CHAPTER IV

1. Under what conditions can we see a beam of light from the side, and why? Describe any occasions on which you have seen a beam in this way, mentioning where and at what time of year.

2. Draw the shadow of a pencil formed by a single lamp on a piece of white card parallel to the pencil (*a*) when the pencil is close to the card, (*b*) when the pencil is a foot or two away. Explain what you have drawn.

3. Make a list of six opaque and six transparent substances. Name as many translucent substances as you can. (Remember that you can name liquids as well as solids.)

4. Why is a pinhole camera never used by photographers? Explain how it is that with an ordinary camera the lens must be arranged at a certain distance from the plate when photographing a given scene, but with a pin-

hole camera the distance of the plate from the hole does not matter.

5. Why do astronomers use a mirror silvered in the front of the glass, while ordinary people use one silvered on the back of the glass?

6. Explain, with a picture, how total internal reflection takes place with a right-angled prism, and why right-angled prisms are used in scientific instruments.

7. Draw a simple periscope in which two right-angled prisms are used instead of two mirrors.

8. Describe Newton's two experiments with the prism and say what they teach us.

9. Draw a picture, putting in the sun, of how you would arrange things to see an artificial rainbow in the spray from a watering hose.

10. What faults do you know of in a single lens which can be avoided by making a lens of several parts? How could you show these faults?

11. What is meant by infra-red rays and ultra-violet rays? What is the chief difference between photographs of a landscape taken with these rays and one taken with ordinary light?

12. Explain why a red poppy looks black in blue light. In what kind of light will a blue book look black? What change in appearance do you expect a stuff that is purple in daylight to show in artificial light? (Purple is a mixture of red and blue.)

CHAPTER V

1. Make a list of some of the chief branches of chemistry, with a few examples of the kind of things with which each one deals.

2. What is the Tyndall cone, and what does it show? Why will ordinary water from a tap produce a faint cone, while carefully filtered and purified water does not produce any effect?

3. Draw any kind of balance, or pair of scales, which you can get an opportunity to examine, and say what it is used to weigh. Describe how the pans are hung to the beam.

4. A weighed quantity of marble is put into a weighed beaker of hydrochloric acid. Next day the whole thing is found to weigh less than the two original weights added together. Why? How could you prove by experiment that what you say is right?

5. Explain what is meant by the Conservation of Matter, and give three examples.

6. A candle is burnt in air for a quarter of an hour. Explain the change of weight that will be found: (*a*) if the candle alone is weighed; (*b*) if the candle together with all the gases formed are weighed; (*c*) if the candle is in a large closed vessel full of air, and the whole thing is weighed before and after.

7. What is the difference between chemical elements and chemical compounds? Give examples of each from things that you see in daily life.

8. Taking compounds of oxygen and hydrogen as an example, explain what is meant by the law of definite proportions and by the law of multiple proportions.

9. How can the two laws named in Question 8 be explained in terms of atoms? What is the difference between an atom and a molecule?

10. Describe briefly the following substances: carbon monoxide, hydrogen peroxide, calcium carbonate.

11. Name four common acids. How would you prove that they have acid properties?

12. Are acids poisonous?

13. Explain, with examples, what is meant by an alkali and what by a salt.

14. To what general classes do the following substances belong: caustic soda, sodium, citric acid, copper sulphate, copper, kitchen salt, sulphuric acid, ammonia?

15. Given a piece of lime and a piece of carbon, how could you prepare a little dry calcium carbonate?

16. Name the chief commercial uses of (*a*) sulphuric acid, (*b*) hydrochloric acid, (*c*) nitric acid.

17. What are the chief properties of chlorine?

18. Describe shortly some ways in which electricity is used in chemical industry.

19. What is meant by reduction, and why is it so important in winning metals from ores? How is it generally carried out?

20. Describe the chief iron ores.

21. Draw a picture of a blast furnace, and describe roughly how it works. What is slag?

22. How can it be shown that metals consist of masses of little crystals?

23. What is the object of the Bessemer converter, and how does it work?

24. Write a short essay on steel.

25. What are alloys? Give five different alloys, and name some of their uses.

26. What is glass, and how is it that it can be blown into bottles while a metal, say lead, cannot?

CHAPTER VI

1. How can you show that (1) paraffin oil, (2) wood, (3) blotting-paper, (4) camphor, contain carbon?

2. How is it that organic chemistry is often called the chemistry of carbon compounds?

3. Write an account of the different forms of carbon.

4. What is petroleum and how is it obtained? Name some of the chief substances prepared from it.

5. Some paraffins are gases, others liquids, and others solids. What kind of chemical difference is there that corresponds to this difference of state? What form do you expect $C_{50}H_{102}$ to have?

6. What is the difference between hydrocarbons and carbohydrates? Give examples of each.

7. How is cane sugar made? Is it different from beet sugar?

8. What is starch? How can potato starch be prepared?

9. Name some important classes of organic compounds to be obtained from plants. How can you distinguish between them?

10. What are the chief uses of cellulose?

11. Give an account of the way in which writing-paper is made. What experiments can you suggest to teach us something about writing-paper?

CHAPTER VII

1. Give two examples of the way in which carbon atoms join up in long strings in organic compounds.

2. Draw the apparatus for demonstrating that CO_2 is

produced during the fermentation of sugar solution, and explain why the CO_2 must come from the sugar.

3. What is meant by "enzyme action"? Give examples.

4. What is the difference between the making of wine and the making of brandv, considered as chemical processes?

5. How is coal gas purified? What valuable substances are produced from coal in a gas works?

6. Describe, with drawings, the two kinds of gas holders.

7. Why is coal tar such a valuable substance?

8. What is the difference between benzene and benzine?

9. What is the general difference in structure between the molecules of paraffin and the molecules of benzene? What are the two main classes of organic chemicals called?

10. What is a catalyst? Give an example of catalysis.

INDEX

PRINTED IN GREAT BRITAIN BY
BILLING AND SONS LTD., GUILDFORD AND ESHER
G1003